The Impact of Weather Conditions and Infrastructure Design on the Mobility of People with Impaired Vision

A Thesis

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DEDICATION

For my family.

Abstract

Nineteen normally-sighted, low vision, and blind pedestrians provided self-reported effects of environmental, infrastructural, and social factors influencing outdoor mobility in the Minnesota's Twin-Cities metropolitan area. Focus groups and interviews were conducted to gather data on challenges associated with year-round, independent outdoor navigation emphasizing winter pedestrian mobility. Study themes included weather pressures (e.g., precipitation, temperature), infrastructural/engineering features (e.g., street, sidewalk, intersection design and maintenance), and safety concerns related to motorists and obstacles. Results identify pedestrian hazard impacts on quality of life and behavioral adaptations visually-impaired pedestrians create to increase safety and efficiency during mobility. Conclusions prompt considerations for urban planners, engineers, community activists, and stakeholders concerning mobility issues for visually-impaired pedestrians. Recommendations are provided to promote equity and wellbeing in pedestrian mobility.

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INTRODUCTION

Following a snowstorm in early February of 2019, Minneapolis- Saint Paul's KARE 11 News Channel surveyed local hospitals and found that well over 100 people had been rushed to emergency departments for snow and ice-related falls—one pedestrian broke a leg by performing an evasive maneuver to leave harm's way from a car that slid through an intersection on ice, “"It just keeps flashing into my head, man. I could have been dead," the patient said.

In recent times, attention focusing on pedestrian mobility, equity, and safety has been increasingly ubiquitous nationwide in regions of dynamic climate change, and in Minnesota (Institute for Transportation and Development Policy, 2018). Pedestrian deaths are increasing nationwide (Craig, Morris, Van Houten, & Mayou, 2019). Extreme weather challenges public infrastructure (Markolfa, Hoehne, Frasera, Chestera, & Underwood, 2019; Measham, Preston, Smith, Brooke, Gorddard, Withycombe, & Morrison, 2011). The literature remains underserved in identifying and understanding the attitudes, behaviors, and experiences vulnerable street users such as visually-impaired and blind pedestrians encounter and the consequential mobility-changing behavioral impacts these episodes can shape.

While previous research has demonstrated various forms of barriers that inhibit or complicate pedestrian navigation in the context of impaired vision, considerations for extreme winter weather in American cities remains understudied. In the wake of increased snowfall and cold temperatures in the

Upper Midwest, community activist groups focused on improving safe and equitable pedestrian travel in the Twin Cities have become more vocal and impactful in advocacy efforts for pedestrians. Additionally, local news coverage has cast a spotlight on the challenges of wintery weather pedestrian navigation and their impacts on safety, quality of life, accessibility, and equity, underlying the need to further research potentially causal factors while gathering information from the affected pedestrians most challenged by these infrastructure conditions (Institute for Transportation and Development Policy, 2018).

The current research examines wintery weather's unique challenges and its impact on quality of life variables for pedestrians with impaired vision.This study identifies and defines normally-sighted participants as those pedestrians with 20/40 Snellen Acuity or better, moderate low vision as reduced visual acuity between 20/40 and 20/400 Snellen Acuity, severe low vision as <20/400 or Snellen Acuity with residual pattern or light perception used for navigation tasks, and totally blind as complete vision loss without utility for navigation tasks. A demographic survey identified moderate and severe low vision and totally blind people that were frequent pedestrians.

Focus groups and interviews in semi-structured formats were conducted with emphasis on disparities in mobility by seasonal weather, infrastructure design, risk and safety perception, and Shared Space development attitudes. Research questions addressed by this study include: 1) Preferences of visually-impaired pedestrians for infrastructure for safety and efficiency purposes; 2) Identifying self-reported safety risks while being a pedestrian year-round in the Midwest and comparing seasonal pedestrian habits based on weather; 3) Understanding and characterizing both perceived and experienced dangers with motor vehicle collisions when walking outdoors; and 4) Surveying opinions and attitudes regarding Shared Spaces. Outcomes for this study sought to discover and characterize mobility and accessibility interventions to bolster quality of life and improve pedestrian experiences for people with visual impairment. The study aimed to document how wintery weather in Upper Midwestern urban areas affects pedestrians and understand which pedestrian infrastructure characteristics hamper mobility for visually-impaired pedestrians in order to identify design issues and recommend remedies to improve pedestrian mobility.

Literature Review

Visual Impairment and Ageing: Demographical Considerations in the 21st Century

The prevalence of visual impairment in the world has increased within the past three decades. Bourne et al. (2017), found in their review a 35%, or 56.7 million people, increase in vision impairment diagnoses between 1990 and 2015. Similarly, researchers project significant increases in prevalence by the year 2050, where some nearly seven million additional United States citizens will become visually-impaired (Varma et al., 2016). Additionally, visual pathologies that contribute to this increase in visual impairments are macular degeneration, glaucoma, retinitis pigmentosa, diabetic retinopathy, and cataract. Age-related eye disorders cause decreased visual acuity, field loss, leading to reductions in mobility, which is defined using Peel's (2005) criteria of "where people move or travel, taking into account the frequency of movement and degree of independence during such movement."

Recent demographics studies and censuses across the developed industrious countries of the world point to an emerging trend: the world's population is aging (He, Goodkind, & Kowal, 2016), and this prompts investigations into the potential outcomes associated with increased age in modern societies. Specifically, ageing's impacts on the population in terms of mobility and the associated safety and quality of life characteristics that come with old age can have profound implications, some of which come in the form of physical stressors. Lord & Dayhew (2001) found that with increased age comes increases in safety risks in falling during locomotion in older age, in addition to factors of bifocal and trifocal use, resulting in reduced visual perception qualities during navigation. Visual perception qualities such as depth perception decrease while using corrective lenses that feature more than one refractive correction, namely reduced contrast sensitivity and distorted stereopsis. These decrements to vision are exaggerated when improper diagnosis or errors are introduced during prescriptive and manufacturing processes. Visual impairment and aging lead to decreased situational awareness, increased proneness to hazards and, therefore, the outcomes are increased hazard monitoring (cost of mental workload, increased stress, lowered quality of life) or falls (Lord & Dayhew, 2001; Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004).

In addition to reduced mobility from physiological changes, human aging also results in consequences for visual abilities and may lead to sedentary behavior (Koster, Caserotti, Patel, Matthews, Berrigan, Domelen, Brychta, Chen, & Harris, 2012). Reduced mobility can have profound consequences on various aspects in experienced life qualities, socioeconomic achievements, social engagement, and both physical and mental health (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004; Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004; Colcombe, Kramer, Erickson, Scalf, McAuley, Cohen, Webb, Jerome, Marquez, & Elavsky, 2004)

Low engagement in physical activity has been shown to increase risk for developing cardiovascular disease, type II diabetes, and even cancer (Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004). Reduced physical mobility can lead to degradations in mental health such as becoming more prone to anxiety disorders, and depression, while decreasing in social connectivity (Augustin, Sahel, Bandello, Dardennes, Maurel, Negrini, et. al.,2007; Kempen, van Rens, Zijlstra, Ballemans, & Ranchor, 2011; Berdeaux, Nordmann, Colin, & Arnould, 2005). Previous work has examined emotional stressors experienced regarding mobility activities and their significance via qualitative feedback from visually-impaired pedestrians (Bittner, Edwards, & George, 2010). For example, aging with vision loss can increase symptoms of depression, anxiety, and decrease ability to engage in daily tasks, in comparison with normally-sighted peers, and some of this can be mitigated by improving mobility (Kempen, van Rens, Zijlstra, Ballemans, & Ranchor, 2011). Previous work found people residing within a 300-

meter radius to pedestrian infrastructure such as expansive sidewalk networks and pedestrian trails were twice as likely to avoid sedentary behavior (e.g., more than 9 hours of inactivity) and engage daily in over 20 minutes of moderate to vigorous physical activity (Frank, Hong, & Ngo, 2019).

Mobility and Safety Concerns in Pedestrian Navigation and Visual Impairment

Civil engineers and urban studies planners often have the "best intentions" for the general population when designing transportation features in the public sphere, but often, these professionals and stakeholders have little understanding how vulnerable street users such as visually-impaired pedestrians navigate and way-find (Williams, Galbraith, Kane, & Hurst, 2014). Several challenging circumstances emerge on the pedestrian infrastructure network due to inconsistencies in engineering designs and pedestrian desires.

Temporary Obstacles, Permanent Stressors

A primary source of stress in safety during pedestrian transportation is obstacles on pedestrian infrastructure. Problematic obstacles that impede safe walking can be fixed, or permanent, and include examples such as streetlight poles and sidewalk restaurant patio furniture or fences, while unfixed, or temporary obstacles, include bicyclists, construction equipment, or sandwich shop advertising folding signs. Each obstacle presents a unique challenge in the physical demands in maneuvering around them; but, for pedestrians that have little or no residual vision for navigation, these obstacles require more mental effort in hazard monitoring tasks (e.g., identifying, understanding, and avoiding the obstacle) as well as physical cane-scanning effort exertion. To the lamentable dismay of visually-impaired pedestrians, obstacles on pedestrian infrastructure appear to be increasing in frequency and by variety in forms.

Obstacles such as telephone poles, fire hydrants, and streetlight posts are permanent and fixed objects in the pedestrian infrastructure network. A pedestrian with impaired vision may encounter them unexpectedly in an unfamiliar area and, unfortunately, collide with them; but, these events can leave an impression on the pedestrian's situational awareness and spatial model of that specific object or sets of related objects that serve as fixed, or permanent obstacles. Permanent obstacles afford the opportunity for visually-impaired pedestrians to create spatial maps of their familiar and frequently traveled routes; however, this affordance is not found in temporary obstacles along pedestrian routes that appear and disappear at random and without cues. These temporary obstacles present significant navigational challenges to safety in mobility and can shape subjective feelings of increased stress and decreased safety. Temporary obstacles can act as barriers to comfortable mobility, which reduce motivation to walk outdoors resulting in potential negative outcomes such as social isolation and increase exposure to mental and physical health risks (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004).

Most people have surely encountered an unanticipated obstacle on sidewalks at one point or another, such as a haphazardly-placed storefront advertising sign for eye exams, or a large upheaval between two concrete squares. Temporary obstacles on sidewalks are quite problematic for pedestrians that rely on internal spatial representations of their navigation routes (Golledge, Klatzky, & Loomis, 2007; Turano, Yu, Hao, & Hicks, 2005; Lahav, Schloerb, Kumar, & Srinivasan, 2015).

An infamous recent example of a temporary obstacle is rentable scooters, which are push-scooters with small electric motors that propel a rider, defined as anyone with a credit card and smartphone, up to 20 MPH (Hollister, Holland, Serrels, & Little, 2018). Scooter use is relatively unregulated by cities in both terms of rider qualifications and ridership locations, which includes standardization of storage areas. The scooter model bases its strength on the freedom and flexibility for users to begin and end a ride (Bird, 2018; O'Brien, 2018). Hazards involving scooter dispersions on sidewalks at random intervals and concentrations result in trips and falls, bumping into scooters or adjacent objects, and potentially being struck by a scooter rider.

Motor Vehicle Traffic and Risk in Pedestrian Navigation

Pedestrians face danger when walking on infrastructure adjacent and intermixed with motor vehicle traffic. Visually-impaired or blind pedestrians experience increased safety risks and hazards due to their reduced ability to visually detect traffic during crosswalk passage on roadways. Intuitively, slower vehicle speeds can increase survivability in motor vehicle and pedestrian strikes that feature head-on collisions. As speed increases above 20 miles per hour (mph), survivability rates rapidly decrease. Most residential speed limits in the study's sampling population region featured 30 MPH speed limits, although, some communities adopt slower travel speed campaigns to reshape traffic safety culture (e.g. "25- Alive, Drive Like Your Kids Live Here").

An extensive review by the American Automobile Association (AAA) Foundation examining the survivability of pedestrians using a sample of 549 pedestrian-involved two-unit crashes from National Highway Traffic Safety Administration crash data found that pedestrians' average risk of severe injury at 16 mph was 10%, 25% at 23 mph, 50% at 31 mph, 75% at 39 mph, and 90% at 46 mph (Tefft, 2011). For fatality risk rate, pedestrians struck by vehicles at 23 mph was 10%, 25% at 32 mph, 50% at 42 mph, 75% at 50 mph, and 90% at 58 mph; when considering the vehicle type that struck the pedestrian, pick-up trucks were as likely to kill the pedestrian when travelling 6.3 mph slower compared to a passenger vehicle (e.g., family sedan) at the same speed (Tefft, 2011). These findings suggest vehicle speeds and vehicle types are of utmost concern in establishing low velocity speed limits in areas with high average daily traffic of pedestrians and motor vehicles alike. Figures 1 and 2 are adapted from Tefft (2011) and depict the stark realities associated with being a pedestrian struck by a motor vehicle by speed.

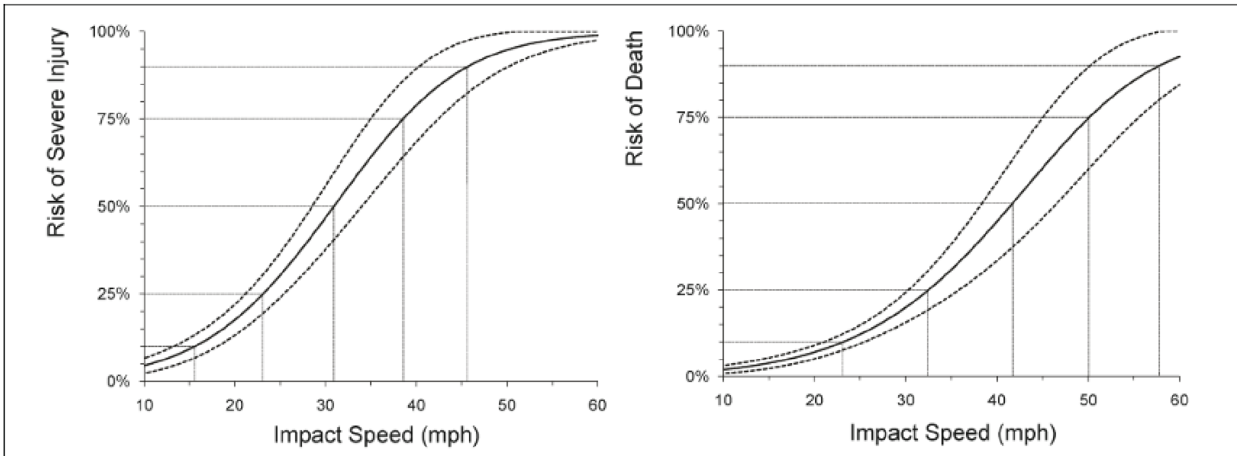

Figure 1. Risk of severe injury (left) and death (right) in relation to impact speed in a sample of 422 pedestrians aged 15+ years struck by a single forward-moving car or light truck model year 1989–1999, United States, 1994–1998. Risks are adjusted for pedestrian age, height, weight, body mass index, and type of striking vehicle, and standardized to the distribution of pedestrian age and type of striking vehicle for pedestrians struck in the United States in years 2007–2009. Dotted lines represent point-wise 95% confidence intervals. Serious injury is defined as AIS score of 4 or greater and includes death irrespective of AIS score.

Figure 1. Pedestrian risk of severe injury and death by vehicle speed profile (adapted from Tefft, 2011).

As automakers move from low-to-the-ground and long-hooded sedans, coupes, and compacts, towards producing high-off-the-ground sport utility, pickup, and crossover vehicles with squared, blunt front fascia, pedestrian collision survivability rates decrease. Figure 2 depicts the significant differences in probability of surviving strikes by passenger vehicles and light-duty trucks. Indeed, vehicle designs appear to be moving against what some experts would suggest as vehicles that would promote pedestrian survivability in the context of a collision.

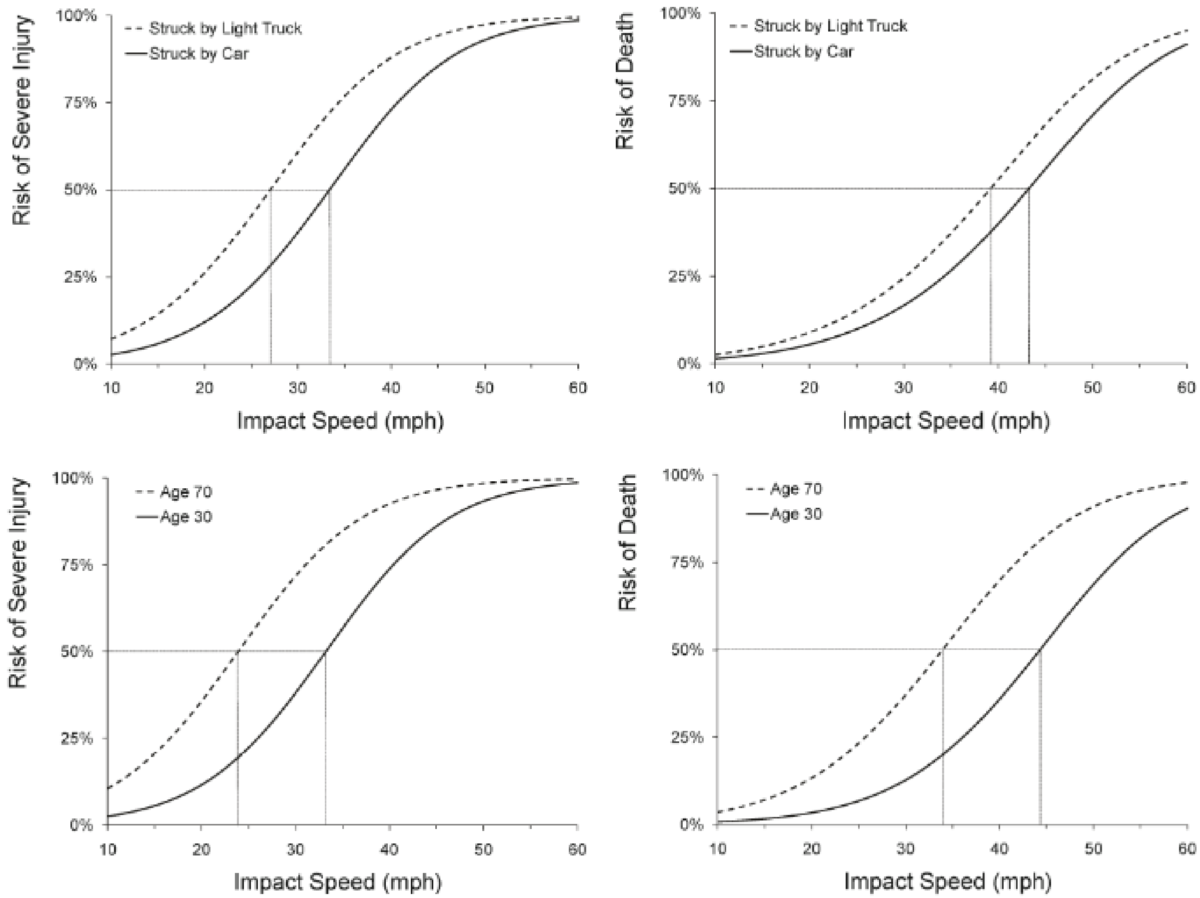

Figure 2. Depiction of pedestrian- motor vehicle strike probability of severe injury and fatality by vehicle type (adapted from Tefft, 2011).

Moreover, some automakers, such as the Ford Motor Company, have made executive production decisions and marketing initiatives to exclusively produce larger trucks while abandoning smaller passenger vehicle manufacturing. These factors, likelihood of death when struck by vehicles, speed limits in pedestrian areas, and vehicle design characteristics, exacerbate safety risks for visually-impaired pedestrians when using public infrastructure and underline the need to incorporate more pedestrian-centric urban planning and public policy to ensure safety and urban ecological wellbeing.

While normally-sighted and visually-impaired pedestrians could benefit from systemic speed limit reductions at motor vehicle and pedestrian areas, an equally hazardous perceptual issue is on the horizon in the form of electric vehicles (EV) (Goodes, Bai, & Meyer, 2009). EVs generate torque using electric motors instead of fossil fuel combustion. In turn, EVs are virtually silent in their operation, leaving only tire and wind noise signatures when accelerating; however, the intensities of sounds generated by wind and tire noise are relatively low, which decreases an observer's ability to detect the presence or localize EVs when on pedestrian infrastructure (Fleury, Jamet, Roussarie, Bosc, & Chamard, 2016). A preliminary study examining blind pedestrians' ability to discern the presence of an EV at both unsignalized and signalized intersection crossings in 2011 found that all make of EVs were difficult to hear, in general, but were more detectable and led to safer gap acceptance distances when the vehicles were traveling above 20 mph Garay-Vega, Pollard, Guthy, & Hastings, (2011). However, EVs traveling under 20 mph were much more difficult to hear, leading to poor gap acceptance rates by blind pedestrians. While EVs and engine vehicles were equally identifiable when travelling past blind pedestrians at speeds over 20 mph, chance rates of identifying the presence of an EV and selecting an appropriately sized crossing gap were found, emphasizing the need to make EVs more audible in their presence on the roadway. More recent work on EV detectability from both normally-sighted and visually-impaired pedestrians' perspective has found equivalent results, suggesting that the EVs' ability to announce their presence hasn't improved despite research efforts and human factors work in building awareness of the issues (Yamauchi, 2014). Equipping quiet EVs with systems that produce an auditory cue to improve their roadway presence has been studied recently with promising results demonstrating improved EV awareness for pedestrians (Fleury, Jamet, Roussarie, Bosc, & Chamard, 2016; Kim, Emerson, Naghshineh, Pliskow, & Myers, 2012). These systems are generally referred to as acoustic vehicle alerting systems (AVAS). EVs are best detected by visually-impaired and blind pedestrians when 100 Hz frequency sounds are projected from the vehicle at a loudness level that is at least 2-3 dB above ambient noise (Yamauchi, 2014; Fleury, Jamet, Roussarie, Bosc, & Chamard, 2016). AVAS technology has piqued the interest of governmental regulatory bodies in recent years following scientific assessment.

Government policies have been made in the United States, Europe, and Asia to require new EV-type vehicles to present auditory cues through AVAS as a means of promoting pedestrian safety (United States Congress, 2010; Yamauchi, 2014; European Union, 2014). In the United States, the Pedestrian Safety Enhancement Act (2010) clearly states that original equipment manufacturers (OEMs) must establish "performance requirements for an alert sound that allows blind and other pedestrians to reasonably detect a nearby electric or hybrid vehicle" while also requiring manufacturers of new EVs to "provide an alert sound conforming to the requirements of the motor vehicle safety standard," detailed in the Act (United States Congress, 2010). A final ruling action by the Obama

Administration in late 2016 declared EVs must have some form of AVAS-type technology to address safety concerns with pedestrian and EV interactions on roadways, citing a projected 2,401 decrease in pedestrian injury events while saving 32 lives in the period between 2017 and 2020.

City areas differ from rural areas in their diversity of roadway types and intersection designs. As built environments, or the general increase in structure and infrastructure development in an urban area, increase in density and diversity, pedestrian activities and motor vehicle volume also increase. These increases have been shown as contributing causal factors in motor vehicle and pedestrian crashes (Miranda-Moreno, Morency, & El-Geneidy, 2011). A study using Seattle as a model found that as pedestrian walkability qualities, such as frequency of intersections, of roadways increase in cities, pedestrian-motor vehicle crash rates decrease. Pedestrian-centric infrastructure, such as reduced width traffic lanes and curb bump-outs reduce driver speeds. Additionally, pedestrian infrastructure alongside one-way roadways were significantly safer and were associated with lower collision rates. Implementing situational awareness cues to drivers in the form of pedestrian signs and static-marked or electronic pedestrian crossing signs provides further safety benefits for pedestrians. However, signalized intersections without pedestrian crossing displays were found to double pedestrian-motor vehicle collision rates, and increased crash risk was found at marked crosswalks and high pedestrian traffic areas. Large lane width has been repeatedly shown to increase drivers' speeds in residential areas. These findings suggest that pedestrian infrastructure design significantly impacts safety while identifying the best-practices civil engineers should employ when designing or modifying roadways. Additionally, findings linking safety to infrastructure design such as those in Miranda-Moreno, Morency, & El-Geneidy (2011) can be used as guidance for vision impairment or vision loss mobility training provided by nonprofits and state rehabilitation services.

Visually-impaired pedestrians often rely on curbs to detect feature boundaries, such as delineations in the ending of curb space and beginning of motor vehicle roadway space (Thomas, 2016). Typically, these curbs are near or larger than 60 mm in height, which is the minimum recommended size (Thomas, 2016). However, current initiatives in city planning involves the removal of curbs in efforts to improve pedestrian experiences in mixed-traffic urban areas that feature motor vehicle thru-traffic and pedestrian traffic. Currently, the City of Minneapolis is considering street designs that remove critical curb boundaries for the visually-impaired, which may reduce safety and situational awareness when independently navigating with reduced vision (City of Minneapolis, 2019).

Shared Spaces- infrastructure design and development in future urban areas

As increased city density is realized moving into the 21st century, pedestrian-based transportation will experience improvement demand from public policy and urban planning stakeholders, which will require stakeholders and governments to specifically attend to equity disparities across age, demographics, and physical and sensory disabilities. Recent innovations that meet these emerging demographic demands in pedestrian equity include the implementation of “smart intersections”, which are typically designed as controlled signalized intersections that feature an audio-visual countdown system that reports intersection cycle times to provide situational awareness status to encourage safe crosswalk passage. The visual displays typically offer “Walk” and “Stop” icons, as well as numeric characters that descend based on the intersection’s cycle time, which is in seconds. Auditory displays provide a synthetic speech voice that counts down the seconds remaining, a feature that not only adds to universal accessibility design principles but, also, improve situational awareness for the visually impaired pedestrian. Intersections equipped with smart technology can also provide contextual cues for identifying roads, in which the intersection is placed, by reporting street names through the auditory messaging. Very recent developments have been made by OEMs, such as Honda, to incorporate vehicle to infrastructure technologies, which provide intersections and cars with information regarding vehicle or pedestrian presence and trajectories (Honda, 2018).

Recently, governments and citizen community activists, alike, across the world have shown enthusiasm in dedicating public spaces that allow for integration of a variety of transportation factors in a shared area, with specific emphasis in restoring the pedestrian’s role in urban areas (Imrie, 2012). This infrastructure design is named Shared Space. During early urban growth in the 1800’s- 1890’s, the primary forms of transportation in cities were by foot, or pedestrian walking, and horse-drawn carriage, and is referred to as the Walking-Horsecar Era

(Hanson & Giuliano (1975), pp.64). These interactions on surface transportation networks were straight-forward in their design and the carriage driver and pedestrian roles on the roadway were intuitive. In recent history, the Shared Spaces movement has been proposed by European countries as a means of increasing transportation efficiency while prioritizing non-vehicle modes of transport in public spheres, ultimately increasing the diversity in user population usages while maximizing return on investment in land allocation to transit purposes. Although Shared Spaces have historically demonstrated success in public approval, traffic throughput increase, and even business profitability in regions proximal to Shared Spaces, these areas lack contextual cues in enabling navigation of people with impaired vision. For example, the Shared Spaces model does not include curbs or curb boundaries which serve as primary elevation and navigation cues for visually impaired persons that rely on pedestrian infrastructure for their daily commutes. Moreover, Shared Spaces roadway designs force the integration of all transportation agents, including passenger vehicles, commercial vehicles, public transports (e.g., metro busses, taxis), mixed-usage vehicles (e.g., rideshare), bicyclists, and pedestrians (Hamilton, 2008a; Hamilton, 2008b). Interestingly, implementation of Shared Spaces roadway designs shows close resemblances to 20th century American city transportation networks, such as San Francisco and New York City, where each of these surface transportation agents coexisted with focuses on efficiency and productivity during the Industrial Revolution transportation booms (Hanson & Giuliano, 1975). Indeed, the metropolitan areas of Minneapolis and Saint Paul, Minnesota, featured complex mixed traffic in the early 20th century. The resurgence of these types of roadways present unique challenges for visually-impaired pedestrians.

Despite enthusiasm for Shared Spaces and similar curb-less infrastructure leveraging mixed-traffic interactions, the impacts and identification of negative consequences for the visually-impaired remain understudied as evident by a brief literature on the topics. Havik, Melis-Dankers, Steyvers, & Kooijman (2012) performed heuristic evaluations of Dutch Shared Space sites using subject matter experts in mobility and accessibility fields, finding significant challenges in mobility and wayfinding for visually-impaired pedestrians when using Shared Space infrastructure.

Hammond & Musselwhite (2013) found resistance from visually-impaired and normally-sighted subjects, alike, to Shared Spaces design in terms of their lack of standard curb design (e.g., “In some places there is hardly any edge to the kerb at all and I came out of a shop on Saturday and my ankle went down off the edge of the kerb.”), ambiguity in traffic hierarchy such as right-of-way and lane of travel locations, and concerns for heading orientation with guide dog navigation aids (e.g., ”My guide dog struggles sometimes to detect any kerb at all. I have quite often found myself at the wrong end ...because my dog has got a bit confused”).

Parkin & Smithies (2012) surveyed and interviewed visually-impaired pedestrians to gather feedback on Shared Space designs and found that while adaptation to these environment layouts were attainable without significant challenges, their findings strongly emphasized needs to provide specific pedestrian safe spaces and design features that bolster tactile, auditory, and obvious differences in color and contrast. Simply put, viability of Shared Spaces rests on more than curb-cuts and truncated dome bump plates for visually-impaired pedestrians.

The current study is focused on identifying pedestrian viewpoints and attitudes towards the potential implications of Shared Spaces in the research region of Minneapolis- St Paul Minnesota, a region representative of urban Upper Midwest culture in the United States of America, and the attitudes and beliefs of pedestrians with visual impairment regarding their safety and utilization perspectives on Shared Spaces.

Seasonal Weather and Impacts on Safety and Mobility during Pedestrian Navigation

General seasonal weather impacts on pedestrian mobility

For pedestrians with impaired vision, navigation strategies must rely on a mix of sensory modalities to safely perform mobility tasks on pedestrian infrastructure. This is done by means of tactile, haptic, and auditory-based methods to compensate for nonvisual cues as primary sensory perception for locomotion. Seasonal weather factors such as rain, sleet, snow, ice, high winds, and extreme temperatures alter pedestrian infrastructure characteristics. For example, summer rain causes a sheen on sidewalks that changes concrete’s surface texture which can reduce tactile perception for a pedestrian with impaired vision. Precipitation and wind can impact an observer’s ability to localize sound, which may increase levels of negative affect and stress and decrease heading orientation skills in pedestrians with impaired vision. Snow also reduces contrasts between sidewalks and street or grassy areas which also complicates mobility for people with visual impairment. Moreover, inclement seasonal weather such as black ice, heavy snow, sleet, and hardened snow packs also present safety challenges and hardships during navigation and its effects are exacerbated for people with visual impairment or vision loss. Wintery weather, specifically ice, snowfall accumulations, and cold temperatures are intuitive causal factors attributable to decreased mobility rates (e.g., trips attempted) and mobility efficiency (e.g., trip duration, trip routing). Moreover, winter conditions can impose increased hazards, obstacles, and traction issues when pedestrians attempt to use sidewalks and crosswalks.

As unforeseeable consequences brought forth by climate change continue to materialize, the Midwest region of the United States has observed significant snowfall and cold temperature trends in recent years. Figure 3 depicts the average snowfall Minnesotans can expect to find across the winter and spring months of November to April.

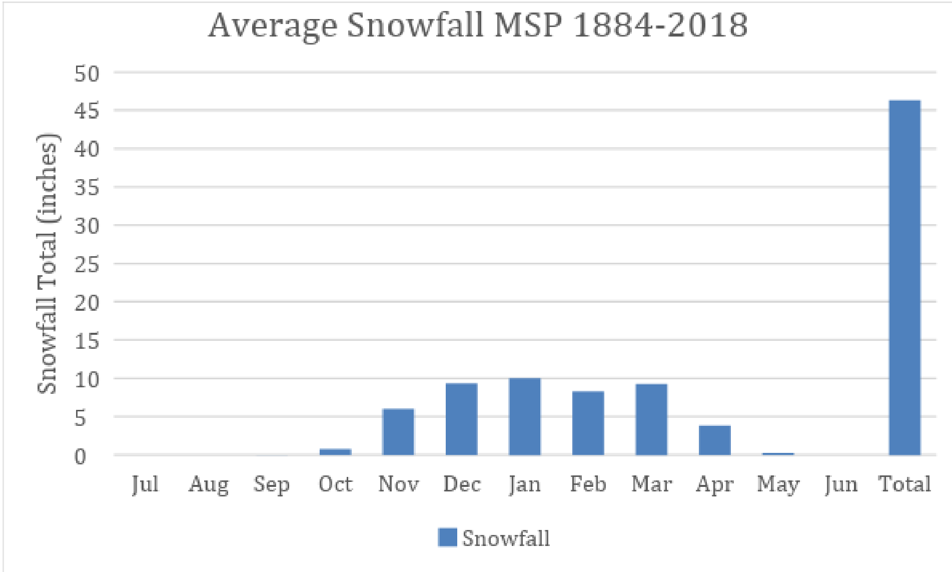

Figure 3. Annual Minneapolis- Saint Paul regional snowfall in inches (generated from data at https://www.dnr.state.mn.us/climate/historical).

A common sunny winter day experience shared by visually-impaired and normally-sighted people is the phenomenon experiencing discomfort from bright sunlight and reflections from snowbanks and ice patches. Lighting disparity between Autumn-Winter and Spring-Summer periods of the year can negatively affect visually-impaired persons, specifically those affected by retinal issues such as Retinitis Pigmentosa, a disorder that creates difficulties in vision under dim lighting conditions, or glare from cataracts. The World Health Organization estimates that roughly 20% of cataracts worldwide can be traced to ultraviolet light exposure, from snow reflection of the most efficient radiation surfaces on the planet (WHO, 2009). Conversely, those affected with nyctalopia report difficulties with their vision when snow cover provides the perception of brightness from sunlight reflection.

The current study objective was to expand on literature relevant to how differing types of public pedestrian infrastructure and human-centered features (e.g., smart intersections, curb cuts, pedestrian refuges) are susceptible to seasonal weather, and the extent to which seasonal weather impedes independent pedestrian navigation and mobility habits for visually-impaired or blind pedestrians. To underline the severity of navigational, mobility, and wayfinding barriers pedestrians in Midwest cities face, see Figures 4 through 10.

Figure 4.Image depicting "black ice" covering a pedestrian sidewalk. Note mix of visible and invisible ice formations and the inconsistency of each covering.

Figure 5. Slush, snow, and ice buildup obscure curb cut and tactile patch on crosswalk.

Figure 6. Commonly found issue: Sidewalk lacking any clearing and path from foot compaction of snow, ~72 hours after snowfall.

Figure 7. Typical sidewalk snow, ice, slush covering and snow mountain at four-way audible-signalized intersection featuring full curb cuts. Roadway completely cleared while pedestrian areas in serious coverage.

Figure 8. Commonplace lack of clearing on sidewalk with heavy foot traffic. Ice, slush, and snow obscure crosswalk.

Figure 9. Completely covered Downtown Minneapolis sidewalk and snow mountains on top of sidewalk regions.


University Ave
THE Naughty Greek

Figure 10. Saint Paul askew four-way intersection with audible signals featuring railroad tracks, full curb cut, and most of truncated dome bump plate obscured by snow and ice while roadways cleared.

Conventional strategies and methods in pedestrian navigation with reduced visual acuity

Orientation and mobility training

Organizations offering rehabilitation services for persons with congenital or adult onset of vision loss may administer courses that teach navigational skills for outdoor walking. These programs that focus on pedestrian navigation and mobility training are generally referred to as Orientation and Mobility Training and are offered by public institutions such as state agencies for visually-impaired and blind citizens. Students in these training courses learn how to safely navigate pedestrian infrastructure, which can encourage increased mobility behaviors. Methods taught include visual-tactile mobility strategies such as shorelining, locating and orienting one's heading relative to traffic auditory cues, and identifying localization of truncated dome bump plates to "square-off" and align with crosswalks at intersections. As a result, Orientation and Mobility Training can increase a visually-impaired and blind person's expanse of freedom in their mobility, which increases safety, social, and physical quality of life subjective perceptions (Keeffe, Lam, Cheung, Dinh, & McCarty, 1998).

Electronic travel aids

The development of assistive technologies has been a consistent theme for engineers over the past two decades, with an increase in promising examples of device prototypes emerging for smartphone markets in recent years. Giudice & Legge (2008) performed an extensive review of such navigational devices for visually-impaired and blind pedestrians and found that conventional electronic travel aids, circa mid-2000's, specifically in early years of PDA and cellular phones, were quite bulky, heavy, and often used in conjunction with additional electronic devices (Giudice & Legge, 2008). Figure 11 depicts Professor Giudice posing with a host of bulky navigation devices circa mid-2000's from Giudice & Legge (2008).

FIGURE 25.1 *A blind pedestrian is using a guide dog and five technologies for navigation. This figure illustrates the need for an integrated navigational system. The guide dog aids with mobility and obstacle avoidance. The compass provides the user with heading information when stationary. The GPS receiver integrates with a GIS database (digital map) to provide position and heading information during outdoor navigation. The talking signs receiver gives orientation cues by identifying the direction and location of important landmarks in the environment. The digital sign system (DSS) receiver picks up barcodes from signs and sends them to a database to facilitate indoor navigation. The BrailleNote accessible computer represents the "brain" of the system, allowing Braille input and speech and Braille output. In theory this device could serve as the hub to which all other technologies interface.*

Figure 11.Professor Giudice poses with various early electronic travel aid assistive technologies, including a guide dog (Adapted from Giudice & Legge, 2008).

Popular mobile smartphone applications such as Google Maps provide any interested pedestrian with navigation information through audio-visual messages from the smartphone. For people with visual impairment or blindness, applications such as SeeingAI and BlindSquare have become integrated with mainstream mobile phones for electronic assistive technology during pedestrian navigation and serve as helpful aids for people desiring more information when walking outdoors. Cutting-edge technologies such as AIRA (AIRA, 2019 United States of America) and Be My Eyes demonstrate a paradigm-shift in assistive technologies, where remotely-based humans facilitate visual search, scanning, and mobility-related tasks for persons with visual impairment or blindness (Figure 12). Cloud or crowdsourcing methods in such tasks are a deviation from locally-based applications installed on a pedestrian’s smartphone.

Figure 12.AIRA.IO augmented reality glasses and smartphone application interface allow for remote connectivity with a human navigational guide service (AIRA, 2019).

METHODS

STUDY OVERVIEW- PURPOSE

The purpose of the focus group and individual interview studies was to gather information and a foundational understanding of challenges associated with independent pedestrian navigation and mobility year-round for people with visual impairment. A set of questions that assessed pedestrian infrastructure usage and utility, safety risks including hazards, obstacles, and construction, wintery weather impacts, and Shared Spaces engineering designs were created to guide semi-structured format focus groups and interviews.

Study Site Geographical location and relevance to research questions

The research location for this study involved recruiting subjects from the Minneapolis and Saint Paul urban, or inner-city and city regions at a neighborhood level. Each participant reported being a frequent pedestrian in these urban environments in Minneapolis or Saint Paul, Minnesota. The results in this study should serve as a representative sample for other cities in North America that feature similar geography characteristics and four-seasoned temperate climates.

Target Population and Sampling procedure

Participant recruitment was performed through Craigslist advertisements, social media platforms (e.g., Facebook, Twitter), and through a participant database provided by the MN Low Vision Research Lab. In total, nearly 30 subjects were identified; however, exclusionary criteria reduced this number to 19 subjects. See Appendix C for Study Eligibility Questionnaire details.

The participant recruitment plan was based on matching acuities by age ranges to form peer groups and to balance individual interview sampling, when possible. Participants self-reported acuity ranges and best known acuity from their most recent exam when applicable. Visual acuity was chosen as the primary independent variable of interest in subjects' visual demographics due to its ease of recruitment and similarity of visual experiences across persons.

SUBJECTS

A total of 19 subjects, 10 males and 9 females with an average age of 40 years old (SD = 15.2), were recruited for participation in the study from November 2018 to May 2019 for focus groups and interviews, with 9 participating in focus group sessions and 10 through individual interviews. The focus group sessions consisted of one normally-sighted group of four people (three males), one two-person visually-impaired group (one male, and one focus group with three legally blind people (two males). Table 1 describes participant recruitment demographic information in the current study.

Table 1.Study Participant Demographics

Group [a]	***N***	**Gender**	**Age Range (*M*, *SD*)**	**Education Level**	**Field Loss**	**Diagnoses**
Normal Vision > 20/40	4	M=3, F= 1	25 – 28 *(27, 1.2)*	HSD* = 1 Master's = 3	N/A	N/A
Moderate Low Vision 20/40 - 20/400	6	M=4, F=2	28 – 70 *(49, 15.2)*	Associate = 2 Bachelor's = 2 Master's = 2	4 Peripheral, 1 Central	Medical error, Glaucoma, Retinitis Puinctata Albescens, Brain Tumor, Optic Nerve Damage, Diabetic Retinopathy, Aniridia, Bardet-Biedl Syndrome
Severe Low Vision 20/400+ visual navigation	6	M=3, F=3	21 – 60 *(41, 12.9)*	HSD = 3 Associate = 1 Bachelor's = 1 Ph.D. = 1	4 Peripheral, 2 Central	Aniridia, Glaucoma, Retinitis Pigmentosa, Hereditary, Macular Degeneration
Totally Blind 20/400+ nonvisual navigation	3	F = 3	27 – 63 *(40, 16.3)*	HSD = 2 Bachelor's = 1	1 Peripheral, 1 Central	Peter's Anomaly, Hereditary

[a]*Groups consisted of subjects with similar visual ability by Snellen Acuity*
**HSD: High School Diploma*

Groups were age and gender matched to the best of the researcher's ability, but persistent recruitment, scheduling, and attrition issues resulted in adopting a mixed-methods study design that used focus groups and individual interviews. To compensate for these drawbacks 10 individual interviews were leveraged to collect insights from visually-impaired pedestrians that could not attend focus group sessions.

Lifestyle and mobility demographic information

In order to ensure that subjects recruited for participation in the research study were specifically residents who had experience with urban area pedestrian mobility, subjects were prompted to report which type of regional area, relative to urban environments, best described where they resided. All subjects lived in the greater Twin Cities area of Minneapolis and Saint Paul, Minnesota.

To ensure subjects were regular pedestrians on public infrastructure outdoors during the calendar year, subjects were asked the frequency of their walking habits for personal mobility on a five-point Likert scale from Never to Every Day. One person reported Hardly Ever (but was contacted regarding this choice and explained this was in the context of inclement winter weather), eight subjects reported walking outdoors year-round for personal mobility most week days of the calendar, and nine subjects reported walking Every Day for personal conveyance on public pedestrian infrastructure. Figure 13 details the range of mobility frequencies reported by subjects.

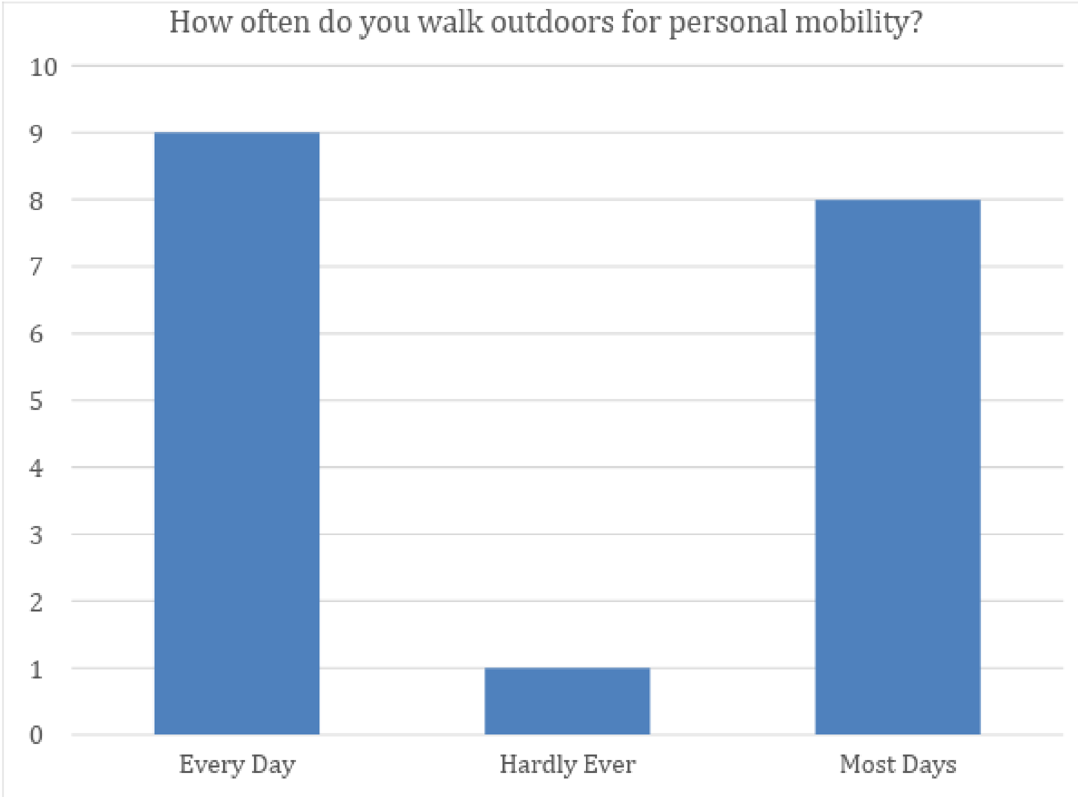

Figure 13. Pedestrian mobility by frequency.

Participant visual characteristics

Color vision and field loss

All normally-sighted subjects stated in the survey that they had normal color vision perception. For low vision and totally blind subjects, five said they had normal color vision, two assumed they had normal color vision, and three subjects reported suspicion they had normal color vision but were not sure if that was objectively accurate. The remaining five subjects did not have normal color vision.

Field loss presents significant constraints and challenges in visual search behavior and the amount of information processing afforded by heading orientation in addition to adverse consequences for navigational efficiency and accuracy in identifying objects in the adjacent environment (Freedman, Achtemeier, Baek, & Legge, 2018). Considering these factors, low vision and blind subjects were asked to report if they had peripheral or central field loss to the best of their knowledge. In total, nine subjects had peripheral field loss, four had central field loss, and two reported not having field loss.

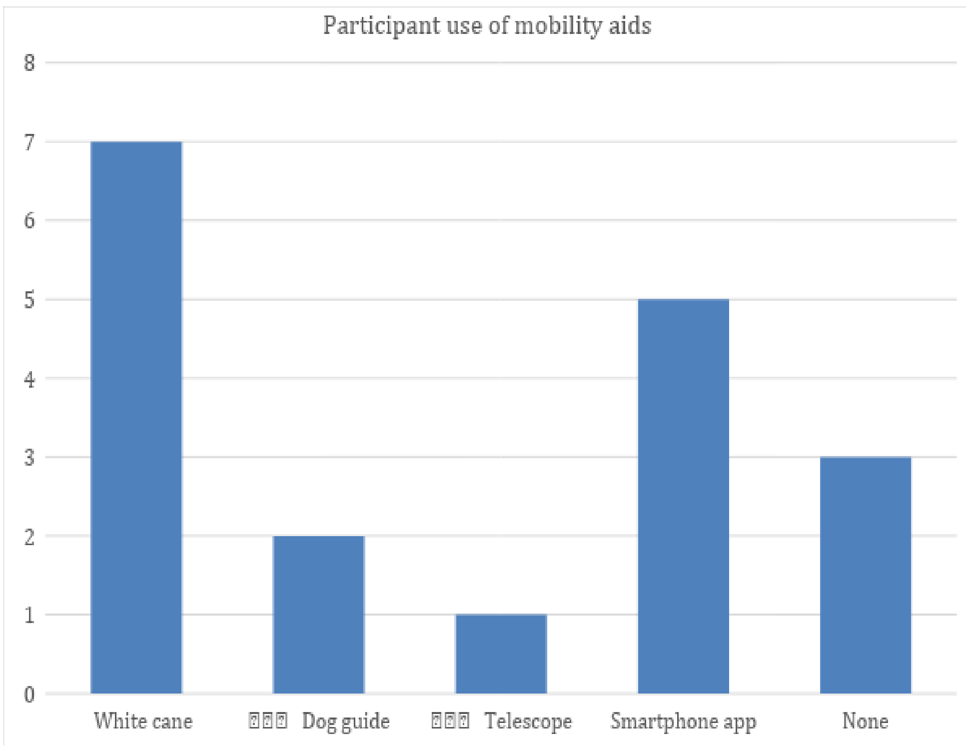

Figure 14.Participant use of independent navigation mobility aids during pedestrian activities.

Gauging mobility aids use for visually-impaired subjects was a variable of interest in the current study, see Figure 14. Seven subjects reported using white canes, two used dog guides, one used telescopes, five used smartphone applications such as Google Maps and Blindsquare, while three moderate low vision subjects reported not using any mobility aids in their navigation activities.

Procedure

Following initial eligibility screening with the researcher, subjects were scheduled for their respective placements in focus groups or individual interviews. In this interim, subjects completed a survey documenting their pedestrian navigation and mobility habits and general demographic information regarding age, gender, and visual ability. Subjects remotely engaged in the study using the ZOOM Cloud Meetings (Zoom, USA) teleconferencing suite, which offered easy accessibility and good usability for dialing in, using the ZOOM smartphone app, or by web browser. All conversations were audio recorded for data analysis purposes. The study's protocol and supplemental materials were submitted to the University of Minnesota's Internal Review Board for review to conduct this research and approval was granted on the basis that this study did not constitute Human Subjects Research.

Prior to beginning each focus group or individual interview session, the researcher administered a consent form detailing the study's procedures, participant expectations, rights, and resources following the study's conclusion, the compensation schedule, and data privacy standards. Consent was recorded using email and a briefing script was read to begin the study. Once participant questions were resolved, the researcher ensured that the Zoom interface was recording the conversations and began delivering the first description of the research questions.

Following each question, answers and related conversation, the researcher would expand on a given item presented by a participant or offer a rhetorical probing question when necessary to encourage more discussion and further information disclosure on the topic's subject matter. Total study durations were one to one and a half hours for individual interviews and one and a half to two hours for focus groups. Subjects were offered a $20 gift card for compensation for their participation in the study. Data collected during the study were archived in private locations and were given non-identifiable codes to ensure subjects' privacy, and included researcher notes taken during the conversation, and ZOOM audio recordings.

MATERIALS

Survey Questionnaire Development

To determine study eligibility and identify subjects' demographics and pedestrian behavior information for study selection purposes, a survey was created and administered once subjects self-identified as being interested in study enrollment. The survey consisted of a block of three thematic categories: 1) establish age and gender demographics information, 2) identify vision demographics primarily by visual acuity and diagnoses items, and 3) document pedestrian navigation behavior and frequency of pedestrian activities and assistive aid usage. Subjects completed an online Qualtrics survey, which was vetted internally for accessibility qualities prior to release to ensure equitable access and ease of completion. The survey consisted of a total of 20 items, which were presented as text entry (e.g., age, gender, pathology type) and multiple choice via Likert-scale questions (e.g., How often do you independently navigate?). A progressive reveal feature was used for visually-impaired and blind subjects who were presented with opportunities to report their type of impairment and associated pathologies. Appendix B contains the survey content for review.

Focus Group and Individual Interview Research Purpose, Questions, and Expected Results

The questions for focus groups and individual interviews were organized into three global categories: 1) Pedestrian mobility challenges, frequencies, infrastructure design usage and reasons for outdoor walking with respect to seasonal weather impacts; 2) Pedestrian safety and risk perception, exposure to traffic hazards, and temporary or permanent obstacles; and 3) Shared Space, curb features, and future directions in city design discussions. The transcript of the questions and subject responses are detailed in the Results section.

Analyses

Thematic factor development

The current study used a mixed-methods approach that follows previous highly-regarded qualitative interview and focus group data analyses methods and reviews to answer research questions while affording opportunities to detail and explore emergent codes during the iterative thematic analysis and coding structure data analyses throughout the data analysis procedure (Braun & Clarke, 2006; Clarke & Braun, 2017;Craig, Klein, Griswold, Gaitonde, McGill, & Halldorsson, 2012; Curry, Nembhard, & Bradley, 2009; Guest, Bunce, & Johnson, 2005; Perry, Thurston, & Green, 2004).

The procedure for determining the coding structure for thematic analyses was based on guidelines from Braun & Clarke (2006), Chen, Nunez-Smith, Bernheim, Berg, Gozu, & Curry (2010), and Maxwell & Reybold (2015). Coding structures were created for each question using the approach described in Chen, Nunez-Smith, Bernheim, Berg, Gozu, & Curry (2010). Each code contained *a priori* themes that reflected hypothesized outcomes, based on literature in pedestrian navigation and mobility with visual impairment or blindness. However, to ensure that the researcher did not bias or artificially force the emergence of a preconceived code, the coding structure afforded for *de novo* establishments of new codes that were adjacent or closely related to the research question that was presented. This integrated method of using *a priori*, deductive coding with grounded, inductive coding approaches for codes and emergent themes in this focus group and interview methods design afforded maximum benefits in data analyses and code identification, thus, improving the quality of the experimental design and subsequent results (Clarke, & Braun, 2017; Braun & Clarke, 2006; Maxwell, & Reybold, 2015; Craig, Klein, Griswold, Gaitonde, McGill, & Halldorsson, 2012). This affords precision and efficiency during data analyses because the analyses plan begins as broad code types and then create space and opportunity to develop sub-codes from the data. During the review of audio conversations, each mention of a theme was documented in an Excel spreadsheet using the participant's identifier code (e.g., B1 for Blind participant 1) under the relevant theme's column. This generated a document containing frequency counts for each time a theme was referenced by a participant within their acuity range group to establish a common code book from which to tabulate quantitative values for all codes that emerged during focus groups and individual interviews. This study used guidance from Braun & Clarke (2006) that suggests the results should contain pertinent, powerful illustrative quotes from the conversation as transcripts in the summary of results.

Focus group and interview data were treated equally in data analysis due to their identical scripts and questions (Patton, 2002; Sanders, 2015). One advantage to using a mixed-methods study design is that individual interviews provide an intimate and private environment that allows for independent expression of ideas, in turn complementing the generation of new ideas in focus groups (Sanders, 2015).

RESULTS

Results from each research question detailed in the Methods is presented below with summaries, details of coding relationships, illustrative quotes, and emergence of thematic elements and convergence across questions. Three general thematic categories consisted of 1) Pedestrian mobility challenges, frequencies, infrastructure design usage and reasons for outdoor walking questions, 2) Risk perception, exposure to traffic hazards, and temporary or permanent obstacles-related questions, and 3) Shared Space, curbs, and future directions in city design. Many responses show interactions with weather factors. Research hypotheses in the format of anticipated outcomes for each question accompany specific interview questions below. The list of questions below were the exact question items posed in each study session.

PEDESTRIAN MOBILITY CHALLENGES, FREQUENCIES, INFRASTRUCTURE DESIGN USAGE

Primary Pedestrian Mobility Challenges at Accessibility or Mobility Locations

1. What are the two largest factors or hardest challenges you face when walking outside? (e.g., seasonal weather circumstances, infrastructure design, sidewalk or crosswalk conditions)

- Do these challenges occur at the beginning and ending (accessibility) parts of the route, during the longer portions of the walk (mobility), or is it a combination of both? Are any challenges uniquely tied to a particular sequence of events on the timeline of your walk?

Expected results: The most significant challenges may be mostly traffic-related in both accessibility locations and travel route areas for normally-sighted subjects, while visually impaired subjects may report more issues with infrastructure design at accessibility locations, such as crosswalk entrance ramps. Winter weather will present unique challenges, and may be mostly cited as buildup of ice, snow, and snowbank debris. The increased difficulty in distinguishing elevation cues, such as curbs, may be cited by those with lower visual ability and older age.

Results from participant conversations indicate the greatest challenges with outdoor pedestrian navigation and mobility across visual acuity groups consisted of: 1) Winter weather factors such as snow, ice, slush, and residual snow from inadequate clearing 2) Seasonal lighting concerns related to contrast sensitivity issues and night-blindness and general visual constraints related to seasonal weather lighting conditions, 3) Construction and hazards borne from active work dangers and both temporary and long-term modifications to pedestrian infrastructure, and 4) Lack of sufficient infrastructure such as sidewalks and design inconsistency and consequential navigation problems. Table describes the primary rankings for issues that cause most significant challenges for pedestrians during mobility activities.

Table 2. Most Severe Challenge in Pedestrian Mobility by Participant

Group	Winter Weather Impacts-Snow, Ice, Slush	Winter Lighting	Infrastructure Concerns	Construction
Totally Blind	2	0	0	1
Severe Low Vision	5	0	1	0
Moderate Low Vision	5	1	0	0
Normal	3	1	0	0

Numerical value indicates one subject's response; zero indicates no mention of factor as the most critical challenge.

All study subjects regardless of visual ability group cited insufficient winter weather clearing as hazardous and as the primary source of largest factors impeding their ability in pedestrian mobility.

> *"Snow and ice are hard because sidewalks are not cleared. Hard to tell where street or sidewalks are. May as well be safe and **walk on streets and hope nobody runs me over.**" (Participant K9, severe vision loss group with residual vision)*

Moderately and severely low vision, and totally blind subjects were more concerned than normally-sighted subjects about their problematic experiences with snow and ice buildup on sidewalks, crosswalks, and at curb boundaries, which was reported to significantly reduce their ability to independently navigate freely around their environments. Winter weather factors such as snow buildup, ice, and slush on pedestrian infrastructure emerged as primary concerns that impede safe passage through crosswalks, sidewalks, and along mid-block journeys during mobility activities shared by all subjects, expressing strongest concerns and frustration with clearing initiatives on sidewalks and at bus stops.

Moderately low vision subjects reported interactions between seasonal weather and lighting pose significant challenges to their safety and willingness to walk outdoors for personal mobility. These subjects were also quite concerned with tripping hazards and slipping on ice on sidewalks and crosswalks and offered insight into the infamous “snow mountain” phenomena.

> *“I’m climbing over 2ft high snow banks* ***just to fall into the bus****. Or even leaving the bus. It’s pretty dangerous and I’m pretty young and flexible, it’d be impossible for physically impaired or aged. This occurs in city neighborhoods.”* (Blind participant)

> “*Guide dog trained to not allow to go over snow bank or bus-* ***I’m really trapped****. Bus stops on city property aren’t ever shoveled in Saint Paul areas!”) (*Blind participant*)*

> *“...sidewalk corners and snow, have to walk out in middle of street to avoid snowbanks on crosswalks,* ***put you into traffic****. Climbing over snow banks, finding paths when blind is very difficult. Use white canes, helps to a certain degree, but it gets stuck in snow.”* (Legally-Blind participant)

Additionally, lighting themes added to the severity of concern for injury risks in winter seasons due to increased difficulty in localizing snow and ice buildup locations on infrastructure. Changes in lighting conditions for subjects with visual impairment were found to contribute to navigational issues during the short days of winter and the lack of contrast between snowbanks, sidewalks, and snow-covered curb cuts. Moderately low vision subjects were most concerned with winter seasons’ reduced daylight conditions which exacerbated night blindness challenges during navigation activities, which was shared with severely low vision subjects, who were also equally as concerned about glare during winter days caused by snow and ice. Totally blind subjects were not impacted by lighting differences for their navigation and instead were primarily concerned with safety issues related to other people or traffic factors during dark hours and, which was shared by half of normally-sighted subjects. The youngest subjects across all groups were least concerned about lighting issues (N = 4). Moderately and severely low vision subjects were concerned about winter lighting's increased glare during the daytime and worsened night blindness at dusk and nighttime, while most totally blind and half the normally-sighted subjects were primarily concerned about safety issues related to other people or vehicles.

> *'I have to shield my eyes all the time because of glare and lighting, I like to walk after a rain because the sidewalks shimmer and I can get around better in summer and spring. Less stressful. Winter affects me a lot because of the obstacles, especially ice, extra reliance on weather channel, snow emergencies, shoveling sidewalks, weather significantly effects running errands and then I use Lyft and Uber in winter." (Legally blind participant)*

One totally blind participant and two normally-sighted subjects were not concerned or had no opinion on winter lighting's effects on pedestrian activities, see Table 3.

Table 3. Lighting Concerns- Winter, Safety, and Daylight factors by Subject Count.

Group	Winter- Night blindness	Winter-Increased Glare	Safety Concerns	No Concern/ No Opinion
Totally Blind	0	0	2	1
Severe Low Vision	2	2	1	1
Moderate Low Vision	3	1	2	0
Normal	0	0	2	2

Count of primary lighting concern by subject; zero indicates no mention.

2. Which types of infrastructure for walking do you prefer to use most of the time (e.g., sidewalk, crosswalks, paths, alleys)?
- Do these infrastructure choices change based on season or weather?
- Are there certain features of the pedestrian infrastructure that you tend to avoid, and do these change in summer and winter?

Expected results: While the preference of infrastructure type may be shared across subjects, those with the least experience and lowest acuity, in addition to normally-sighted older subjects, may report using features that are more technologically advanced (e.g., curb cutout, smart intersection). Those with lower visual ability with more navigation experience and those with higher visual ability may report using all types of infrastructure features with similar preference in the summer, but change those preferences towards more technologically advanced options during the winter in order to bolster safety and maintain similar rates of exposure. Overall distance ranges and areas of covered regions should not change between normally-sighted and visually impaired groups, as found in Owsley et al (2014), but they should differ in their exposure rates and willingness to navigate, with the most marked differences occurring in winter months.

3. Which sort of infrastructure features do you see as the safest, easiest, and most worry-free when walking outdoors? Does your perspective change when thinking in terms of summer and winter seasons, and if so, how do they differ? How about examples of the most dangerous, stressful, or concerning infrastructure types you encounter when walking outdoors?

Expected results: All groups may report the highest levels of safety, ease, and lowest stress using newer infrastructure features, such as smart intersection crosswalks with lane markings and bollards, which may be most important to pedestrian navigation tasks when wintery weather and reduced daytime lighting complicates navigation across age and visual ability groups. Those with normal vision and highest age, highest age and visual impairment, and least experience with or without visual impairment may report conventional infrastructure lacking features such as curb cut outs as the most dangerous and stressful areas. These concerns should increase in wintery weather, as debris and reduced daylight may complicate the navigation task.

Pedestrian refuges between medians, and curb cuts were thought of as the safest, easiest, and least stressful types of pedestrian infrastructure but their lack of ubiquity across the Twin Cities was mentioned as a shortcoming. Subjects reported that modern technologies and engineering interventions such as “smart intersections”, or modern Audible Pedestrian Signals, which provide auditory cues on when pedestrians are safe to cross a signalized intersection were helpful infrastructure aids to their safety and comfort during mobility activities.

> *"I walk further when there aren't any [Audible Pedestrian Signals] crosswalks, I have to walk an extra 10 blocks round trip to cross. I often jaywalk because of this."*

Although curb cuts emerged as core topic of discussion across the study as a safe and comfortable intervention during navigation, all subjects with impaired vision reported aversion to using the type of curb cut that spans the entire radius of the sidewalk intersections, referred to as "full" curb cuts. Fully-rounded curb cuts were reported as a detriment to mobility for subjects with significant vision impairment due to a lack of clear orientation to the crosswalk path. This was reported to decrease a subject's situational awareness and spatial representation of their route across the intersection. The curb cuts that are most desired by all subjects with impaired vision.

Sidewalks that feature curb and general elevation or tactile boundaries were mentioned as a most-trusted type of pedestrian feature, as well as parts of the city where grassy regions between sidewalks and streets could be found, as each added increased situational awareness of where the subject was relative to traffic. Subjects emphasized these features assisted with tactile navigation methods, such as shore-lining with white canes and probing surfaces with footsteps.

An unexpected set of problems discussed by subjects with impaired vision was related to public transit services in both Minneapolis and Saint Paul. Subjects reported frustration with the lack of accessible information regarding rider alerts in the winter. Physically locating the sidewalk near the curb to enter the bus and leave the bus safely during winter when snow and ice accumulated were examples of challenges with bus systems cited by all subjects with impaired vision. Snow piles reaching hip to head height, referred to as snow mountains, located at bus stops were mentioned here as an issue that severely inhibited one's ability to use busses. Snow mountains presented additional challenge for pedestrians that use guide dogs for navigation. Many examples of experiences and associated safety concerns related to busses and public transit were brought forward:

> *"…Metro transit bus stations are horrible- they should do a better job- do they even clear? Rider alert signs are not visually accessible, bus goes by you, they can see me with white cane but they go by- how do you alert a blind guy, the bus doesn't know!"*
>
> *"I'm afraid to use [bus station shelters in rain because if I'm in there a bus driver won't see me so I miss the bus- also, decorative crap you can't see through the shelter like advertisements make it so they [bus drivers] won't see me…[because of worry and stress, I gotta stand out in the rain."*
>
> *"I had to stand in road to cross, cross the street and climb over snow bank to wait for bus, then climb over mountain of snow to get on bus. Rider alerts are hard, waiting for long periods of time and someone walks by saying oh there's a sign, there's not a bus coming."*
>
> *"I can't see ice on the sidewalk and there is little icy cleanup. This is quite common to experience. It is very hard for me to walk even though I'm very careful and walk slow. There is always a possibility I fall, I fell and got a fracture in my ankle [recently]."*
>
> *"I'm more prone to fall in winter time, trip over snow bank on infrastructure that should be cleared. [There's] city snow plow and metro communication issues."*
>
> *"Busses are the least accessible form of transportation in my opinion. Busses don't stop in right place, hard to navigate to each bus as a blind person and ask if it's the correct bus, not punctual. Bus stops, so much snow it's hard to navigate the banks. Sometimes it's almost impossible you know, I need to catch it before us leaves!"*

Results emphasize the importance of public transit for mobility in persons with impaired vision, in addition to highlighting significant problems with bus transit's rider alerts and lack of bus stop snow clearing during winter.

4. Does seasonal weather change your perspectives on safety, stress, and ease of walking? How does weather change the frequency of your walking patterns?

   Expected results: Seasonal weather changes will add stressors, increase difficulty walking, and reduce perceived safety levels across all groups. The severity of these perceptions will increase with age and impairment severity. Navigation patterns will be adversely affected in those with older age and reduced visual ability, while normally-sighted younger subjects may not report a marked difference in their habits.

The discussion specifically assessing seasonal weathers' impacts revealed that all low vision and totally blind subjects viewed wintery weather, specifically ice and snow buildup on pedestrian infrastructure such as curb boundaries and sidewalks, to be the most problematic aspect in independent mobility activities in the Twin Cities. This finding was originally discovered at the beginning of the discussions as a primary factor in mobility challenges; however, this question item sought to expand on further details on potential causes and scenarios in winter weather. Overall, all subjects reported that wintery weather changed their perspectives on safety, ease of mobility, varying degrees of mobility habit changes, and were concerned about falling, slipping, or becoming hurt in winter pedestrian mobility. Moreover, most of the subjects across groups (N = 15) reported they changed their frequency of mobility during the winter due to slipping and injury concerns. For example, most subjects without normal vision stated that they were more likely to take a rideshare or public transit option instead of relying on pedestrian mobility during winter, despite additional challenges in accessing these services due to snow and ice accumulation on infrastructure leading to access points. Normally-sighted subjects were less likely to take public transit instead of walking outdoors in the winter, comparatively.

RISK PERCEPTION, EXPOSURE TO TRAFFIC HAZARDS, AND TEMPORARY OR PERMANENT OBSTACLES

1. Are there certain pedestrian or vehicle traffic conditions, times of the day, or areas that you tend to avoid, or are on highest alert?
    a. Thinking about these responses, how do they change based on the winter and summer months? Does the weather impact the extent to which you avoid them or feel as if they're most unsafe?
    b. Thinking about daytime versus night time, especially in the winter months when darkness arrives before 5pm, would you say your walking patterns change due to safety concerns?

    Expected results: Rush hour in the morning and evenings will result in higher avoidance and, therefore, lower exposure across visual ability and age; however, professional obligations and related reasons for navigating at this time may differ in age and visual abilities, as older subjects may not need to navigate for work. Based on previous findings, such as Owsley et al (2014), visual impairment may not reduce the amount of distances covered; but, those with low acuity may avoid unfamiliar areas. Overall, winter may reduce exposure rates in general, with exposure rates decreasing as age increases and visual ability decreases. Wintery weather may exacerbate avoidance in navigation tasks, which will further decrease exposure rates in all groups, with the most profound impact within the lowest acuity group. Exposure rates during the day may remain consistent across seasons in all groups, however; these rates will significantly decrease at night as a function of lower acuity and increased age.

Most moderately and severely low vision pedestrians were primarily concerned about morning and evening rush hour times of the day due to motor vehicle and pedestrian traffic, which was reported as being significantly more problematic during winter months due to lighting conditions. All subjects were notably more concerned about driver inattention and distraction during rush hour than other concerns and cited driver impatience as a motivating push to drive unsafely near pedestrians. Closely following driver aggression citations were general infrastructure concerns such as problematic scenarios involving people clustering near curb cuts and bus stops are significant challenges to their safety and efficiency in independent navigation, due to the obstructions and muffling of traffic or traffic signal auditory cues that promote safe mobility. Additional impeding factors to safe navigation were often cited as crowds were reported by all subjects with impaired vision, with severe low vision subjects expressing strongest distress during these circumstances due to increased noise and amount of people on pedestrian areas. Table 4 presents themes brought forth by subjects and the frequency count of each theme's reference during discussion related to times of day and areas problematic for pedestrians. Importantly, many subjects with impaired vision who stated concerns with rush hour vehicle and pedestrian traffic, in addition to lighting concerns (e.g., vision or personal safety), desired to change their working hours or changed them as an adaptation to these challenges, N = 9.

Table 4. Frequency of Themes Reported during Rush Hour and Time of Day.

Group	Vehicle Traffic/ Driver Aggressiveness	Pedestrian Traffic	General Noise	Infrastructure	Winter Lighting	Rain/Snow Interactions (sound, traffic)
Totally Blind	3	3	2	3	0	2
Severe Low Vision	5	3	2	5	2	2
Moderate Low Vision	4	2	1	4	1	1
Normal	4	0	0	1	1	0

Values indicate mention counts across participants; zeros represent no mention of theme.

Normally-sighted subjects did not report concerns with pedestrian traffic, noise concerns, infrastructure design challenges, or interactions involving rain or snow and noise and traffic with the same frequency or concern intensity as evident in Table 5. Moderately low vision and totally blind subjects offered feedback that year-round weather factors such as rain, snow, and ice changed mobility habits and often encouraged more frequent use of public transit services such as busses and Metro Mobility services.

Bicyclists and scooters were cited as frequent issues near and on sidewalks and crosswalks for all subjects with impaired vision. Both were reported to be difficult to localize or anticipate because of their lack of sound generation.

Daylighting changes that winter months bring were again mentioned to be significant factors in changing mobility habits and navigation behaviors for visually-impaired subjects. Normally-sighted subjects did not share such significant differences in perspectives on safety, ease of walking, and general wellbeing. A handful of visually impaired and blind subjects stated they changed their work schedule to avoid more exposure to winter evenings outdoors for personal travel, and those subjects who could not afford to change their schedules, wished they could have this flexibility in the future. Specific reasons for avoiding pedestrian activities in dark hours of the day and night included night blindness concerns and public safety weariness. Some visually-impaired subjects stated that they were impacted by low lighting conditions during the winter months; however, they noted that it would not be an aspect of life that would inhibit their freedom in personal mobility, while blind subjects reported interpersonal safety concerns as their most worrisome lighting factor. Blind subjects did and did not state any concerns regarding daylighting changes on their mobility habits during winter months. See Table 4.

Contrast issues and glare from bright winter day sunlight was also an issue reported by both visually-impaired and legally blind pedestrians, and these factors contributed to their negative outlooks on winter lighting conditions.

> *"Night-blindness makes it hard to navigate, but I feel safer at winter night because the white snow is like turning on 50 lamps during the day. It's nice it's dark because of my contrast issues."*

2. Have you ever been involved in a collision or near-miss with a motor vehicle?
   a. What were the circumstances, such as time of day, weather, and location? Could you describe the conditions and the infrastructure layout?

Expected results: Near-misses and collision rates will increase with age, exposure rates, and visual impairment. An interaction similar to Owsley et al (2014) may appear in low exposure rates and severity of visual impairment, where the lowest acuity and least amount of navigation exposure underrepresent conflict episodes.

Every visually-impaired or blind participant reported at least one event where they were nearly struck by a motor vehicle while using pedestrian infrastructure (Table 5).

Table 5. Frequency of Pedestrian's Reported Collisions with Vehicles and Near-Misses.

Group	Been Hit	Near Misses	Evasive Maneuvers	Vehicle Struck Cane	Harmed Guide Dog
Totally Blind	1	3*	3*	1	2
Severely Low Vision	2	6*	3*	3	1
Moderately Low Vision	4	6*	4*	1	0
Normal	0	2	0	0	0

**Denotes multiple occurrences per subjects.*

Passenger vehicles encroaching into the crosswalk space when pedestrians have right of way and public transit vehicles such as busses and light rail trains are problematic and safety concerns for subjects with reduced visual acuity. Although many pedestrians in this study reported constant white cane and guide dog navigation aid use, when walking in these scenarios, their experiences suggested that such cues did not change driver behavior enough to reduce risks to collisions and injuries at crosswalks or intersections. For owners of guide dogs, traumatic experiences are probable and have made lasting impressions on their perspectives of safety during mobility activities. Guide dogs were reported as being traumatized and disabled mid-crosswalk which results in retirement, as well as being struck themselves and having serious, potentially disabling, injuries as a result. White canes being run over by motor vehicles was an emergent theme for many low vision and totally blind pedestrians, and those who had not experienced this event in their own lives were well-aware of the likelihood that they will experience it at some point based on stories from peers.

> *"Yes- few times where I had right of way and the car lurches forward and I've had to jump back, or getting midway through intersection and cars drive in front of me and dog forces me backwards…Six months after I got my [guide] dog she did get her paw ran over by driver, didn't end career but she did get hurt. Cars trying to beat me through the intersection because they think they have the time to get through parallel traffic it mainly happens on stop sign intersections, or signalized and cars turning try to beat me. I know cars can see me because it happens in the day. Sometimes in rain and at night. Worse in winter weather because people are in more of a hurry because the weather slowing down."*

> *"Electric vehicles and right turns at crosswalks can hit me, my guide dog can help me but not always… Have been clipped by cars with my cane. Left turns are more problematic on one-way streets "*

> *"[I've had] two hits, several close calls where I was crossing and car encroached and I had to use my cane to hit the car. Twice when I almost hit by a train- one time it was dark 5am downtown in Minneapolis, I crossed with group of people and they were crossing faster than me, and I heard the horn right beside me and*

ran onto sidewalk. [Other train event] train call didn't say east/westbound, chime was very late- why? I jumped to avoid train."

"Yes. I was trying to cross the street and a bus drove into the crosswalk and struck me and I almost fell over. I've experienced cars that will drive into crosswalk and hit with cane."

"[Close-calls with cars] Hundreds of times. Typically, it's a car making a turn in front of me with right of way assertion."

"I almost got hit by a car when I ran across the street. Cars turn in front of you when you're in the crosswalk."

"Left hand turns are seriously dangerous; no [driver] eye contact, distraction, drivers nearly hit me and not see me, sometimes it feels like they're very close…so impatient"

According to low vision and totally blind pedestrians, left and right turns at intersections, are the most dangerous crossing scenarios based on experiences with close-calls and vehicle strikes. EVs were cited as particularly concerning by one moderate low vision pedestrian due to their lack of auditory cues at intersections.

"I have been hit an unsignalized intersection [Como Avenue, Southeast Minneapolis] because I follow other normally sighted people who think it safe, but I have to make judgements by myself often. I will make wrong decision often, most cars stop or slow, but one driver wasn't paying attention and made an emergency braking. I now use a cane to add more attention to me. I have had close calls with bikes."

3. Are there previous experiences where you have had to perform an evasive maneuver, such as quickly stepping out of the way, to avoid being hit by a vehicle, fellow pedestrian, or bicyclist?
   a. What were the circumstances? (Could you describe the scenario?)

*Expected results***:** All subjects may report an instance where a motor-vehicle has warranted an evasive maneuver, with those without vision aids in navigation might experience disproportionate frequencies of these events.

All but two subjects, one severe low vision and one totally blind, had at least one experience where an evasive maneuver was needed on their behalf to avoid being hit by a motor vehicle. Those that did not report a specific evasive maneuver experience referred to the time(s) they were struck, instead.

> *"There's been close calls, honking horns scare the shit out of me because you never know where its coming from, especially if it's from you or other cars. In crosswalk, car honked right in front of me when I had right of way, scared the shit out of me."*

Typical responses included maneuvers such as jumping backwards to avoid a car turning left or right in an intersection.

> *"If I am crossing on the sidewalk on a two or four lane road, left turning cars pulling in front or behind me, this is very stressful and they paralyze me. Makes me wonder if I veered or did something wrong." (Blind participant)*
>
> *"...Cars in intersection trying to turn and they try to drive in front of you because they're more important than you are." (Legally-Blind participant)*
>
> *"Many, many times -- if I can, I'll remove their side mirror." (Visually-impaired participant)*

Bicyclists were cited as a general problem for safety during mobility, with some experiences involving bike path and pedestrian sidewalk crossings. One participant with moderate low vision stated that bikes are often an issue because they are not detectable with sound and bicyclists tend to not pay attention for pedestrians crossing bike paths.

4. Let's think about temporary obstacles you encounter while walking. These can be vehicles obstructing a sidewalk or crosswalk, a bicyclist on the sidewalk, traffic equipment placed in your walking path, or even snow and ice buildup on the ground. How frequently do you experience temporary obstacles? To which degree do these obstacles become problematic when you're walking? Which are the most severe?

    Expected results: Frequency should be related to exposure rates across participant groups. Temporary obstacles may prove most problematic for those with visual impairment, specifically those with lowest exposure rates and experience levels. Obstructions such as traffic illegally encroaching into the crosswalk regions will be reported as increasingly problematic as age and impairment increases. Winter weather will be reported as a compounding variable in the extent to which temporary obstacles prove to be problematic to pedestrian navigation.

Temporary obstacles in the form of construction equipment are extremely problematic and ubiquitous in the Minneapolis- Saint Paul urban areas according to subjects.

Construction obstacles included signage, hoses, random equipment, cones placed on sidewalks, pedestrian bridges that contain elevation changes or immediate turns that are unannounced, and vehicles or other large features such as scaffolding or material piles. Overall, construction signage noting detours or alternative routes are “meaningless because I can’t see them until I’m at the sign or fence” for many severely low vision and totally blind pedestrians. Construction emerged as a primary, universal theme for explaining safety challenges and mobility efficiency with low vision and blindness. Common sidewalk obstacles subjects reported being unpredictable and dangerous include:

- Sidewalk café patios
- Sidewalk café advertisement signs
- Mobile food carts (e.g. hotdog stands)
- Scooters placed randomly
- Sidewalk scaffolding for apartment buildings
- Temporary overhead ceilings
- Temporary pedestrian bridges near construction
- Temporary bridges that add abrupt corners
- Dock-less bicycles placed randomly
- Trash or recycling containers
- Vehicles obstructing sidewalk or crosswalk
- Temporary construction signs
- Temporary and long-term construction equipment
- Bicyclists on sidewalk or in crosswalk
- Skateboarders on sidewalk
- Patio chairs and tables
- Poles adjacent to temporary obstacles
- Heaved segments of concrete on sidewalks
- Snow and ice buildup

- Inattentive pedestrians
- Short fences around trees, such as tree planters
- General slope changes

Weather issues compounded temporary obstacles in the summer and winter. For example, rain in the summer months when construction is most common attenuates auditory cues that low vision and totally blind pedestrians rely on, causing additional stresses and fears for getting hurt while walking on sidewalks. Summer was also unique in the types of temporary hazards that appear, as sidewalk shop and scooters, bicyclists, and pedestrians on cell-phones are more common and significant issues relative to winter months.

> *'[Construction] very frequent in summer, a lot of places I go have construction- this is most frequent, problematic, and severe for safety hazards."*

> *"Construction is the absolute worst because of the danger factor there. Disorientation from sidewalk ending. Second is things that businesses have and contractor trucks near sidewalk-- canes and dogs won't locate them and you hit your head…. flags on businesses or hanging pots – all these are the least predictable [temporary obstacle]."*

> *"I will see construction cones or bulldozer and pedestrian detours as a frustrating obstacle. Big snow mountains, I would also say trash/debris on the roadways near sidewalks or on sidewalks, some divots that cause tripping… People on phones are temporary obstacles, including me, when walking."*

> *"Mostly the obstacles I run into are icy conditions and snow buildup, worst is the black ice. I have fallen on my butt."*

> *"I can't plan for scooters. I've tripped over parked ones. Sidewalk shop signs, restaurant patios, temporary construction sidewalks. Anything that's out of the ordinary. I always see snow and ice when walking in the winter and they're rarely shoveled."*

> *"I have struck vehicles because of a vehicle in the crosswalk. Construction equipment, bicycles, scooters placed anywhere, and all of the sidewalk furniture- sandwich shop signs, restaurant patio, sale signs- there's just stuff everywhere! Sometimes signs on posts at head height can bonk me in the head. Scooters are awkward tripping hazards."*

> *"Canes stuck in patio furniture."*

“I’m careful about the light rail ice in winter time, without the new train barriers experiment on platform makes me feel I can easily slip and fall onto rails.”

“Construction sign protruding into sidewalk, they pop up all over and I had to call 311… sidewalk café tables and such, always problematic because of scatter. I avoid downtown areas these days. Scooters- too quiet and they’re startling.”

People clustered on sidewalks were cited as temporary obstacles. Distracted pedestrians, specifically those using phones when walking on pedestrian infrastructure, were cited by many subjects as being problematic and cause bumping events or congestion at crosswalks and bus stops.

5. Have you ever had an injury or stressful experience with orientation loss, tripping, or bumping into other pedestrians or bicyclists while walking? Where did these occur? Can you provide the circumstances of these events?

*Expected results***:** Most subjects across age and visual ability may report stressful experiences with conflicts while walking, however; visually impaired persons with more experience may report more conflict occurrences based on exposure and may share conflict avoidance tactics learned from these experiences. Older subjects with normal vision may share similar experiences with older subjects with visual impairment. The location of incidents may occur most frequently at access points, such as crosswalk and sidewalk ramps, for subjects with the lowest acuities due to traffic volume and bottleneck at these locations. Mid-block locations may prove most problematic for those with lower experience and acuity, as conflicts at these locations on the sidewalk may be most surprising and more unexpected than access points.

All low vision and totally blind subjects had experiences with injuries, typically numerous and severe in nature, due to orientation loss, tripping, slipping, missing steps, and by contact with pedestrians and bicyclists or scooters when using public pedestrian infrastructure. These events happen at access points and at random intervals at mid-block location. Common instances of injury and falling or tripping include:

- Tripping on construction equipment on sidewalks
- Slipping on ice and breaking bones
- Nearly falling into an open sewer manhole

- Delivery truck obstructing sidewalk resulting in dog maneuvering around the truck and into traffic, yet still struck the truck
- Bumping into other pedestrians or bicyclists, skateboarders illegally on sidewalks
- Being tugged across streets by well-intentioned pedestrians

> *"When people mean well but are annoying and need to step back- someone grabbed me by the arm and took me across the street when we didn't have right of way, I had to elbow them to get free because I was put in a dangerous situation, had guide dog. One time someone led me across when I didn't want to cross and they grabbed me across, this was disorienting."*

> *"I nearly fell into an open manhole, with nobody else around…"*

Skateboarders and bicyclists on the sidewalk were common themes cited often by all subjects with impaired vision and some reported having been struck on multiple occasions by skateboarders and bicyclists. Distracted pedestrians, roughly defined by subjects as pedestrians staring at their smartphone and looking downwards while walking is an increasingly common safety threat on sidewalks, even when a low vision or totally blind pedestrian uses salient navigational aids such as white canes and guide dogs on leashes. Subjects that used canes or guide dogs said that navigational aids are a good deterrent attempt to gather more space when walking on sidewalks, but this is not always an effective tool:

> *"People [are] not moving [out of your way] with canes on sidewalks, so you had to walk on the road to get around them- people walking 3-4 wide."*

Each type of temporary obstacle represented an injury risk due to falling, tripping, slipping, or bumping. Many subjects reported these specific obstacles because they had experiences with colliding with them and having some degree of injury following.

Despite such a broad array of potential harms on conventional pedestrian infrastructure, subjects took their experiences with pain and injury in stride, with one resilient totally blind participant stating:

> *"One thing about being blind is I still want to have a life, so there's going to be bumps and bruises."*

Inconsistency in the design of curb cuts, both fully-curved intersection boundaries and squared-off curb cuts, were mentioned by low vision and totally blind subjects as significant temporary obstacles because they impose unexpected cognitive burden during navigation tasks. Moreover, missing and improperly placed bump plates were noted as problematic. Bump plates not aligned with crosswalk paths in the direction of the opposite sidewalk were unnerving for many subjects. When these bump plates are askew or offset relative to the other curb cut, subjects with impaired vision reported finding themselves wildly off trajectory or jaywalking towards opposing traffic. Subjects once again emphasized that winter weather exacerbates these because ice and snow are often obscuring tactile cues from bump plates.

SHARED SPACE, CURBS, AND FUTURE DIRECTIONS IN CITY DESIGN DISCUSSION

The final questions specifically assessed the role of curbs and elevation cues, Shared Spaces street design, and future direction discussion.

Significance of curbs and elevation boundaries

Specific discussion on curbs and elevation boundaries or cues was included in the transcript to gather further information on their importance for pedestrians with impaired vision.

1. Let's think about the role curbs play when walking. Do curbs or having different elevations between sidewalks and traffic lanes define safe regions by which you can comfortably walk within? Do curbs, curb-cutouts, or other street elevation cues aid your navigation? How is your walking impacted by snow, ice, or slush buildup at curbs?

   Expected results: Reliance on curbs and street elevation cues will increase with low acuity. Snow-related debris will be a detriment to all pedestrians and may become more significant in lower exposure rates, lower experience (i.e., younger visually impaired), and older age.

Normally-sighted subjects were indifferent towards the impacts of curbs on their personal mobility habits and safety when encountering them or not during walking activities. However, the expected results underestimated the significance curbs hold in value for navigation for people with impaired vision. For visually-impaired pedestrians, specifically those with severe low vision or total blindness, curbs and curb cuts serve as primary features by which situational and spatial awareness are possible during navigation on pedestrian infrastructure, as concisely stated by a blind participant:

> *"In Minnesota, we have two things: sidewalks and streets. Snow, ice, slush takes me longer to figure out [where I am at] at curbs in the winter. Curbs are a pretty important safety feature to me. [Curbs] help with my orientation on where I need to be going."*

As predicted, winter weather accumulations of snow and ice on curb features and at curb cuts was expressed by subjects with impaired vision as being a significant safety and mobility efficiency concern. Specifically, curbs and curb cuts with truncated dome bump plates that get covered in snow or ice present major challenges and safety hazards for all low vision or totally blind pedestrians. Injuries were prevalent across participant groups, with falls and risks of falls or injury cited unanimously, one severe low vision and one moderate low vision subject both reported bone breakage based on slips related to ice buildup on sidewalks caused by insufficient grooming or attributable to relevant construction hazards and general lack of sidewalk maintenance.

> *"Snow ice slush is extremely problematic, not only is it piled up on curb cuts but it freezes, so you can't feel bump plates. Snow plows toss snow piles on the shoveled parts." (Legally-Blind participant)*

A severe low vision participant familiar with the open-spaces layout found in Minneapolis and reported this type of roadway was problematic for locating pedestrian areas and it increased stress of injury. These concerns increased with the presence of snow and ice.

> *"I rely on curbs for navigation purposes- Nicollet Mall has no delineation, even the textured strip they used doesn't work and is hard to detect, much worse in winter. No heating on sidewalks made it worse. Curbs [with] snow and slush make it harder to detect where the curb is. It is much more stressful and fear of falling; one time I took the bus home and I walked home and I got really scared that I couldn't be independent rather than metro mobility because the snow wasn't cleared and [was] heavy and hard to detect curb." (Legally-Blind participant)*

Subjects across acuity groups were keen on how city snow plow trucks can often create profound challenges along curbed areas of the roadway, which typically result in large "snow mountain" barriers that are stressful to encounter with reduced acuity or blindness. Many (N = 11) of these subjects expect to encounter these problematic ice and snow mountains during their navigation activities, however; anticipating snow barriers does not increase mobility ease or safety, unless the person decides to avoid walking altogether and select a rideshare service such as Uber, Lyft, or Metro Mobility.

> *"Curbs do provide a barrier from cars, but they don't affect me much in summer. In winter you have to jump over puddles or snow drifts, garbage in snow drifts." (Visually-impaired participant)*

> *"Curbs help me know where the street is. Street corners that are rounded [with full curb cuts] are disorienting." (Blind participant)*

Low vision and totally blind subjects were brief in their assertions that curbs, elevation cues, and appropriately designed (e.g. squared-off) curb cuts were some of the most relied on pedestrian infrastructure features increasing safety while navigating, in addition to adding comfort. These results expand on ideas mentioned during discussion involving primary mobility challenges and winter weather factors.

Shared Spaces Design

Subjects were given a prompt to imagine the implementation of Shared Spaces in the Twin Cities area. Many subjects had experienced Shared Space in Europe, Michigan, or locally with the recent Minneapolis Downtown Nicollet Mall redesign, and the design was not well-received regarding their perceived negative impacts on pedestrian safety by every participant across acuity groups. Normally-sighted subjects were also displeased with Shared Spaces design and reported similar concerns elicited by low vision and totally blind subjects.

2. The shared spaces idea of infrastructure design is becoming more popular in European countries. This layout is without feature boundaries, such as elevated curbs, and incorporates all types of transportation agents, like pedestrians, cars, and busses, share the open road. How would you feel if there weren't any curbs when walking? How would this curb-less walking environment change your perspectives in winter versus summer?

Expected results: Shared spaces may receive the highest praise with younger, normally sighted subjects due to their comfort with pedestrian infrastructure and willingness to accept change. People with impaired vision may be hesitant to resistant to shared spaces given their experience using curbs and the comfort elevation cues may provide. Additionally, those with obstacle, vehicle, or bicyclist conflict episodes with lower acuity will oppose shared spaces, noting perceptions of dangers with mixed traffic.

"I'm not going to walk, I'm going to call uber or metro mobility. I don't want to engage in this area based on what I see with distracted driving and bike texting."

Driver inattention and distraction was cited as a potential problem that would present safety risks to pedestrians in Shared Spaces. Bicyclists were also mentioned as likely sources of conflict as well, with one participant explicitly stating concern for texting and distracted bicyclists on the roadway. Normally-sighted subjects were concerned for their safety in Shared Spaces for similar reasons.

"I would be finding a different place to walk, I'd have to backtrack and go somewhere else. If the road were shared. This doesn't sound very safe. With winter weather, it would be astronomically worse. Curbs are important."

"They have to somehow create barriers. For me, this would be really challenging because [guide] dogs rely on curbs and left side of curb or street my dog wouldn't know. With a cane I'd be too nervous and would hit businesses to avoid being by cars, very stressful and wouldn't want to walk very far."

"It would make guide dog nervous, would make shorelining hard or impossible. The dog would get nervous because they don't feel a purpose. "

Possibilities of orientation loss due to lacking curb, elevation cues, or tactile patterns were raised by all subjects with impaired vision. Concerns for snow clearing on Shared Spaces infrastructure was also cited as a cause for concern in safety and comforts during navigation for all study subjects, and emphasized by low vision and totally blind subjects.

> *"[Shared Spaces are] setting pedestrians up to fail, I can't imagine a shared space. Significantly more stressful to have these features, especially in winter. Will drivers have a good model of delineation? It sounds way too stressful-- and I'd do everything I could to avoid that area. It'd be interesting to see if pedestrian fatalities increase in that setting."*
>
> *"Us blind people use curb to make sure dogs are close to it, trail with canes and shoreline, other people in wheelchairs use curbs as guides. It would be kind of scary, experienced it in Michigan and there's a lot of benefits for having raised curbs. Its tactile feedback."*
>
> *"This doesn't sound very safe. With winter weather, it would be astronomically worse. Curbs are important."*

These results indicate that pedestrians at large are resistant to Shared Spaces-types of public infrastructure.

Existing Infrastructure and Future Design

Serving as the last question presented in focus groups and individual interviews, the closing point of discussion presented subjects with an opportunity to express their opinions on what is working, what isn't working, and what types of interventions or big-picture, holistic changes should be made in terms of pedestrian mobility and associated public government initiatives.

3. In your opinion and based on your expertise, what are we doing in pedestrian infrastructure design that is beneficial and helps or encourages your walking habits? On the other hand, what sort of designs or features fail to meet their intended purposes, and what actions can be done to make improvements?

Expected results: All subjects may comment on increasing ubiquity of specialized pedestrian infrastructure features, such as curb cutouts and smart intersections, as positive examples. Upkeep, lack of new construction, and inconsistencies in where features are constructed may be complaints from normally-sighted subjects, and these opinions may be shared with those of all ages with visual impairment.

Once more, snow and ice were primary sources of discussion. All subjects with impaired vision expressed their desire for property owners and government agencies to increase snow clearing efforts city-wide, citing safety concerns and accessibility constraints associated with snow and ice on sidewalks. A totally blind participant stated this sentiment most concisely, adding:

> *"… snow barriers are issues. Shovel sidewalks, bus stops, curb cuts to make it possible to get on sidewalks and make it [walking] safer. I'd be more open to take public transit n winter if it were cleared-- this is for everybody."*

Further comments echoed these general themes regarding snow, ice, and slush buildup on sidewalks, crosswalks, and points of access, with some moderate and severe low vision subjects emphasizing the safety concerns for those with reduced vision or physical disabilities as especially at-risk to infrastructure surface conditions in winter.

> *"No shoveling for bus stops….makes it really difficult with wheelchairs and blindness to get around in winter. [It's a] seven out of ten in difficulty to get on the bus [in the winter]. Snow mountains, ice, and the refreeze makes it unpredictable to know where the ice is. I think they can definitely do a better job with that but I understand the budget issues."*

Additional focus was placed on the underlying infrastructure design and maintenance concerns subjects had across visual abilities. For many, the lack of standardization of infrastructure design features, such as inconsistency in the ubiquity of audible intersections and the types of sounds they emit within Minneapolis, inconsistencies with tactile feedback at curb cuts and the variety and inconsistency by which curb cuts are placed, and the lack of expectancies in which type of intersection signals will be present along their journeys. All low vision and totally blind and three normally-sighted subjects wanted to see smart intersections with audible messages at every intersection. Crosswalks with placards and flashing beacons were also cited frequently by severe low vision and totally blind pedestrians, as these features increased comfort and feelings of safety when crossing.

> *"I like that there are plenty of audible or automated crosswalks, but they need to improve on standard signalized intersections. I want to see more grass boulevards and improved sidewalks. I also hope to see more transit reach. Expanding transit around the city and to suburbs. Sometimes the city isn't good to clear out bus stops, especially when there's snow forecasted."*
>
> *"More audible crosswalks, more crosswalks in general, talking busses. More rapid transit and LRT."*
>
> *"I like grids, downtowns are better. annunciations and language the same. Light rails having two sets of tracks and you're done. Parallel tracks with sidewalks, nothing weird and wonky that doesn't match straight line of travel."*

Additional discussion points regarding improvements that should be made to existing infrastructure design and transportation services included additional curbs and elevation cues, curb cuts that are squared-off to best indicate crosswalk heading and orientation for accurate and safe passage, audible crosswalk implementation city-wide, and incorporation of infrastructure features such as haptics at audible crosswalks to assist with deafblind pedestrians to improve their mobility experiences.

Snow build up at bus stops, bus driver behavior, and lighting conditions at access points were again reiterated and mentioned by all visually-impaired pedestrians multiple times;

> “*Public transportation is why I moved to the city [Saint Paul]. Once I stopped driving, I was trapped in the rural area. When it’s not there, like in the suburbs, to have to sell your home and move away from your friends because you don’t have PT and a disability sucks. But, things like the busses are useless if you can’t get into the bus at a bus stops. You can feel like… trapped. “*
>
> *“Bus drivers don’t call out bus numbers when they know a low vision person is on the bus. Filing complaints didn’t work. I miss my connections based on bus driver not saying which bus it was. I now call the ambassador program, they meet me at bus and help me transfer-- this reduces stress of standing [at bus stops waiting].”*
>
> *“Bus stops need more light!”*

Interactions with bicyclists and bike paths were cited as issues that need resolving, which may be in the form of barriers such as bollards to block vehicles or bicycles from entering sidewalks.

All subjects across visual abilities want to see more standardization in sidewalk design characteristics, specifically width conformity. This was cited most frequently as necessary for severe low vision and totally blind pedestrians, who mentioned that consistency is necessary for “trailing” sidewalks during navigation. Additionally, textures at and on sidewalks and sidewalk boundaries were mentioned by legally and totally blind subjects as being an intervention that could improve comfort and ease in navigating independently:

> *“…Light rail makes me unsure where to exit or where to enter. We need more textures to identify light rail sidewalks areas when you are or aren’t going to the train.” (Legally blind participant)*

Further discussion on curb cut design types and inconsistency was brought up visually-impaired subjects, but with stronger sentiment by severe low vision and totally blind subjects, revealing thoughts such as curb cut implementation as an example of “People trying to do the right thing, but realize after that it makes it dangerous for the blind," and that some problematic, new types of infrastructure designs' "Intended purpose is for the best reason, but then not everything is thought of."

Miscellaneous strategies governments could take or solutions that can benefit pedestrian mobility with low vision and total blindndess that were suggested included: increased lighting on all city sidewalks using solar-powered lighting systems; reflective paint on crosswalks and curb boundaries to enhance visibility for the visually-impaired caused by Retinitis Pigmentosa; and more emphasis on road diets (e.g., reduced lanes, lane width reduction) and streets with bike lanes. A surprising circumstance regarding social interactions and guide dogs was brought up by one totally blind participant: "fake" service dogs have become pervasive to the extent that other pedestrians will harass guide dogs in public.

> *"I get bullied by general public on the streets because I don't look blind, fake service dogs make us look bad. I get rude comments because pet dogs make a bad name for service." (Legally blind participant)*

The subject mentioned potential remedies to mitigate such harassment from the general public would be to make the approval process for service dogs more rigorous in training requirements or ban the selling of illegitimate service animal harnesses.

AGGREGATE THEMES ACROSS RESEARCH QUESTIONS

The current study identified a core set of themes that emerged from the focus groups and individual interviews following rigorous thematic analysis using participant-provided data. The following theme summaries summarize general sentiments and viewpoints from the perspective of moderate and severe low vision, totally blind, and normally-sighted pedestrians that walk independently in their day to day lives.

Pedestrian walkway conditions and winter weather

An overarching theme across focus groups and individual interviews consisted of factors related to the lack of clearing and grooming public pedestrian infrastructure has during winter months in the Minneapolis- Saint Paul city regions. Moreover, the lack of snow, ice, and slush clearing at the infrastructural locations of sidewalks, crosswalks, curb and curb cut boundaries, and bus stops were the most frequently mentioned codes and emergent themes throughout the study. Participant testimonies reported in the current study as illustrative quotes reinforce the importance and severity of these surface-clearing shortcomings and the significant consequences pedestrian activities on these surfaces can impose.

Access to Public Transit Services and Busses

Busses and associated difficulties accessing, disembarking, and interacting with bus drivers was not an original theme established in the formation of the study; however, busses and bus-related experiences became the second-most cited coding items during focus groups and individual interviews. Bus-related interactions and activities on behalf of low vision and blind pedestrians can introduce conflict, while low vision and blind pedestrians are often strongly concerned about safety risks associated with standing alone at bus stops, being passed by a bus driver, failing to be notified of a route modification due to printed rider alerts without Braille, or tripping or falling on “snow mountains” as they enter a bus or as they leave; this population often heavily relies on the efficiency and structure of bus routes as a means of independent personal conveyance. The current study’s results unearthed a bus riding population at odds with the nature of the bus service itself. Further work needs to examine bus-pedestrian conflicts and interactions using low vision and blind pedestrians as a population sample.

Temporary Obstacles

Blind and low vision pedestrians encounter significant challenges in completing navigational tasks, and unexpected temporary obstacles are frustrating due to their variety and ubiquity on sidewalks in urban areas. All subjects with low vision reported temporary obstacles accounted for many opportunities for harm and stress when walking outdoors. Construction obstacles, pedestrians, bicyclists, scooters, skateboarders, and business-related obstacles were most commonly reported, however; weather such as rain, snow, and ice were also mentioned as temporary obstacles that significantly impacted observed and perceived safety during navigation.

Motor Vehicle and Bicyclist Collision Threats

Discussions with blind and low vision pedestrians provided insights into the specific types of motor vehicle and bicyclist crash scenarios that were most common and carried most concern during mobility activities on pedestrian infrastructure. Left and right- turning vehicles that featured pedestrian crosswalks were the most frequently cited example of crash risk and experiences with collisions and near misses by blind and low vision subjects. These types of scenarios, specifically left-turn crashes at four-way intersections, are overrepresented crash risks for bicyclists and motorists as well.

Low vision pedestrians frequently reported that many of their concerns when crossing street intersections were related to impatient drivers that led their unsafe decisions to “try and beat” visually-impaired and blind pedestrians through intersections. While blind pedestrians did not have affordances to see this type of driver behavior, their statements regarding unsafe driver behaviors mirrored those from low vision subjects. Furthermore, experiences involving vehicles attempting to cross in front of and behind obviously visually-impaired pedestrians at left-turning events were of particular concern for subjects and researchers alike. These emergent themes are indicative of a systemic safety culture issue between motor vehicle drivers and pedestrians.

Curb Features

Curbs and other elevation cues were one of the most recurrent themes and one of the highest importance from the perspectives of visually-impaired and totally blind pedestrians in this study. Clear elevation delineations free of snow and sufficiently textured or painted for increased contrasts are the best types of curbs, according to low vision and blind pedestrians. Curbs afford shorelining, orienting heading angle at crosswalks, and establishing general regions of safety during navigation. Any curb-presence disrupting factor, namely snow, ice, and slush at or near curb boundaries, were cited as extremely problematic and of the highest importance for public and government clearing efforts during winter.

Shared Space Perspectives

The current study replicates thematic findings in previous literature on pedestrian outlook regarding Shared Space initiatives (Hammond & Musselwhite, 2013). All visually-impaired pedestrians, specifically those with profound and total vision loss, were understanding of the principles behind increased efficiency that Shared Spaces could provide but were quite concerned about their impacts on safety for pedestrians with visual impairment or vision loss. The lack of elevation cues, tactile cues, and a mixing of cars, busses, bicyclists, and pedestrians were cited as primary reasons why Shared Spaces may prove to be dangerous for low vision and blind pedestrians.

Future Desired Changes

Despite numerous citations of concerns and problems with existing engineering interventions and assistive public infrastructure technologies, study subjects were generally pleased with efforts to maximize pedestrian experiences in the Twin-Cities Highest satisfaction was found with audible messages at modern intersections, beaconed crosswalks, squared-off curb cuts, tactile cues such as truncated dome bump plates and rail platforms, and LED lighting features near high-traffic pedestrian areas. The general sentiment across all pedestrians, specifically those who rely on non-visual navigational cues, was that of promoting more of the same in terms of their desired changes to pedestrian infrastructure, moving forward. Increased consistency and ubiquity of audible intersections and public transit access points and the winter weather clearing efforts of all pedestrian infrastructure was the primary thematic element that bound all future desired changes together, conceptually.

Temperature

Interestingly, temperature was not a theme that emerged from any focus group or individual interview over the duration of the study. Despite having held the research sessions during an extreme winter in terms of double digit negative Fahrenheit temperatures, with multiple days reaching nearly -60*F with wind chills, subjects were seemingly not concerned with temperature as a meaningful factor that impeded pedestrian mobility or safety perceptions. Perhaps the lack of temperature's emergence as a theme in pedestrian mobility is evidence towards the theory of genetic advantages Minnesotans assert having regarding winter-temperature resiliency.

Discussion

Pedestrians with visual impairment and varying degrees of vision loss are changing their lifestyle habits, such as work schedules, cities of residence, and the extent to which they leave the house for social activities exclusively because of impassable winter weather conditions on public pedestrian infrastructure in the Twin Cities. Such behavioral adaptations to winter weather's impacts on sidewalks and crosswalks have the potential to significantly decrease quality of life characteristics unique to navigating with impaired vision or blindness relative to pedestrians with normal vision. While pedestrians with normal vision may reduce their mobility habits and willingness to walk outdoors in the winter, the increased hardship of independently navigating with reduced visual ability compounds and exacerbates safety risks. In turn, increased risks of physical harm and may put these people at disproportionately increased risk for physical and mental health issues due to reduced physical activities (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004; Colcombe, Kramer, McAuley, Erickson, & Scalf, 2004; Colcombe, Kramer, Erickson, Scalf, McAuley, Cohen, Webb, Jerome, Marquez, & Elavsky, 2004).

The current study's thematic analysis methodology using focus groups and individual interviews featuring normally-sighted, moderate and severe low vision, and totally blind pedestrians provided opportunities to gather profound access to the experiential and introspective insights associated with engaging in outdoor mobility in a conventional Midwestern urban environment. Although the nature of the study and research goal outcomes were quite positive, data revealed a stark and unnerving set of perspectives borne from traumatic experiences, such as tripping or slipping on ice on pedestrian infrastructure and breaking bones, having guide dogs run over or traumatized from a near-miss collision with a motor vehicle, from the visually-impaired pedestrian perspective that are disconcerting. Specifically, these included the stressors imposed by experiences with motor vehicle collisions and near misses, episodes with guide dogs being struck or traumatized by misjudgments in crossing acts, disrespect and alienation from public transit services, and social isolation caused by daunting pedestrian infrastructure conditions. Indeed, these results demonstrate dthat pedestrian mobility is a both a dangerous and tough task to perform in urban areas.

Moreover, collected data and subsequent results generated from this study afford a foundational precedence by which stakeholders in government, community, and research domains can build upon in future cooperative efforts to improve the quality of life for city residents, specifically visually impaired pedestrians as vulnerable transportation agents by focusing on issues addressed in this study.

Participant data helped form the emergence of significant environmental impacts on their independent pedestrian mobility habits and attitudes towards personal navigation use-cases and frequencies: Seasonal weather precipitation (e.g., snow, ice, rain) and associated sidewalk clearing, pedestrian infrastructure medium and maintenance condition lighting conditions year-round in terms of sunlight, refraction from snowy coverage, and infrastructure light sources, unpredictable and disruptive temporary obstacles (e.g., construction, summer sidewalk novelties), and point-of-service public transit accessibility challenges (e.g., bus stops and rider alerts, snow clearing, safety risks). While previous research examining other transportation agents, namely bicyclists, found that issues with themes related to those identified in this study were particularly selective personal boundaries in nature (Spencer, Watts, Vivanco, & Flynn, 2013), the current study's sample and larger transportation agent population type do not have the privileges of mobility choices that typical normally-sighted pedestrians, bicyclists, and motorists have at their discretion. That is, all subjects in this study reported their sole-reliance on independent pedestrian navigation as their means of engaging with the greater society alone. Such a distinction should emphasize the importance for forming initiatives to address the various critical challenges and constraints visually impaired pedestrians encounter in their daily lives year-round in urban Midwestern environments. Examples of infrastructure design and maintenance relative to weather conditions -- low-hanging fruit -- come in the form addressing the costliest consequences to society at large, which may coincide with visually-impaired pedestrians' most desired improvements; for example, simply coordinating local department of transportation or city snow plow routes with regional public transportation managers could easily rectify the "snow mountain" occurrences at transit stops placed on pedestrian infrastructure. Snow clearing in general is a paramount issue of concern for all pedestrians in this study, which is an exacerbated challenge for pedestrians with severe vision loss or complete blindness. Yet another example of a minimal-cost, maximum safety return would be city works personnel performing sidewalk grooming efforts to remove hazardous upheaval features on highly-travelled sidewalks, which was an additional concern from subjects in this study, some of whom had injuries related to tripping on such features. A final candidate solution to mitigate pedestrian stress and minimize exposure to safety risks from temporary obstacles is to establish new legal policies regulating diverse types of sidewalk clutter that private entities freely impose on pedestrian infrastructure, in addition to designing new interventions for roadway, sidewalk, and building infrastructure construction sites to reduce the surprising and disorienting impacts these operations have for visually-impaired pedestrians.

All low vision and blind subjects provided compelling arguments against the integration of Shared Spaces in their environments because of navigation and safety concerns. Normally-sighted subjects were less resistant to the ideas of Shared Spaces; however, they were concerned about safety risks and the risks of vulnerable road users, such as visually-impaired pedestrians or people with physical disabilities that may be at increased risk of harm from motor vehicles or bicyclists. Furthermore, concerns regarding a city's ability to clear snow and ice from shared spaces was raised by subjects, which are credible points given their dissatisfaction with pedestrian infrastructure maintenance with conventional infrastructure. These findings replicate sentiments expressed by visually-impaired and blind pedestrians discussed in findings by Hammond, & Musselwhite (2013).

While these recommendations are general in nature and easily described on paper, their implementation costs and administrative efforts are modest and should not pose concerns for city governments that are truly focused on principles of goodwill and safety towards citizens' wellbeing and quality of life metrics. Moreover, grandiose visions anticipated by current urban planners and public policy stakeholders are untenable in practice if current, outdated pedestrian infrastructure fails to meet basic needs for a significant subset of the population. Indeed, it is not only visually-impaired pedestrians that incur injuries, stress, and lifestyle changing constraints from various weather-infrastructure interactions in cities. While engineering advancements such as Shared Spaces appeal towards removing the significant motor vehicle mainstays in urban roadways, such concerns involving traffic were secondary to weather and infrastructure design and travel conditions. Making cities more walkable requires a systematic level of cooperation to improve qualities of life for every person using public infrastructure in urban ecosystems.

Future Work

This study exclusively recruited moderate and severe low vision and blind pedestrians that self-reported normal hearing abilities without any evident hearing impairment that impeded their ability to process speech. The subjects stated they had what they believed to be average, non-impaired hearing during the screening process with the researcher. The author acknowledges that this study's sample is only a subset of the sensory impaired population that uses outdoor navigation for pedestrian activities. Further work should be encouraged to identify common stress, safety risk, and weather-based causal factors that focus on dual sensory loss and deafblind pedestrians.

Methods provided for planning, designing, recruiting, proctoring, analyzing, and reporting qualitative research via focus groups and individual interviews were painstaking reviewed in the design of this research study to conduct the research in the best possible manner. However, due to contention within the discipline and the numerous niches found within, a one-size-fits-all approach could not be found in respect to thematic and coding analyses in this study. While the current methods lend themselves to replication, which the author strongly encourages calls to replicate this study, one meaningful change in data analyses could be made to dive deeper into this study's subject matter is to analyze the participant data in terms of latent semantic analyses instead of face-value semantics. Latent semantic analyses afford a richer understanding of underlying themes and comprehension of linkages between questions, themes, and codes in the context of the discursive nature found in this study's qualitative methods of interviews (Braun & Clarke, 2006; McNamara, & Kintsch, 2009; Dumais, Furnas, Landauer, Deerwester, & Harshman, 2003; Foltz, Kintsch, & Landauer, 2009). For example, the differences in results by conducting latent semantic analyses of participant data would provide opportunity for increased depth in causal relationships and discovery of intersections between affect, snow, and introspective views on personal safety and wellbeing (McNamara, & Kintsch, 2009). Examples demonstrating promise in latent semantic analyses of discourse data gathered in this study are evident in illustrative quotes throughout the Results section, which detail contextually-rich instances between concepts of safety, emotion, and crystallized memory via experience.

One such example future research should examine is of the trend where conventional assistive technologies are designed to make use of the non-affected sensory modality, typically auditory in the case of visual impairment or vision loss, but this approach presents unique design challenges for persons with dual sensory loss due to constraints imposed by hearing impairment. Persons with dual sensory loss cannot rely on functional auditory perception that aid visually-impaired and blind pedestrians. In the context of pedestrian navigation, these persons may not make use of auditory aids such as the popular audible signalized intersections discussed in this study. Furthermore, pedestrians with dual sensory loss may be more prone to hazardous events that would be otherwise avoidable in the case of only having vision loss, such as the discussed example of crossing an intersection while using a white can as a navigation aid and having a motor vehicle strike and break the cane. In this example, which emerged organically in the focus groups and individual interviews, pedestrians with residual vision report the affordances of being able to navigate through the intersection to safety citing auditory cues in determining their orientation relative to directional traffic flow, whereas pedestrians with dual sensory loss would not have similar affordances due to their inability to perceive sound, and therefore traffic and their heading orientation. Future researchers are encouraged to identify overlap between visually-impaired and blind and dual sensory loss pedestrians and the convergence of hardships experienced during outdoor mobility and the seasonal weather factors that impact safety and quality of life.

LIMITATIONS

Participant recruitment and participation

Qualitative research, specifically interview methods, rely on small sample sizes to generate findings that generalize to the larger population. Consequently, these types of studies provide the opportunity for error when asserting a general sentiment or finding to the greater population. Given the breadth of potential causal factors associated for visually-impaired and blind, not all experiences or findings can be applicable to all visually-impaired and blind pedestrians with certaint; therefore, the current study’s findings should be discretionary in applicability to all visually-impaired and blind pedestrians, despite the researcher’s effort in recruiting a diverse population.

Recruitment proved difficult for blind subjects, specifically procuring age and gender-matched subjects with similar visual acuity and without hearing loss. Due to this recruitment constraint, the researcher chose to hold individual interviews with subjects to collect data. While the study format differs between both methods, literature exists stating benefits to complementing focus groups with individual interviews and given that analyses were identical in procedure and practice, no concern for study confounds are believed to be necessary (Patton, 2002; Sanders, 2015).

A majority of subjects in the current study were educated at a Master’s level, which presents minor concern for data generalizability from this study sample to the population, however; variation in experiences of job commitments, regional and neighborhood living environments, and pedestrian transportation routes ensure these subjects were highly varied from one another and thus representative of the greater Minneapolis- Saint Paul and Midwest urban area pedestrian demographics. It is possible the study has serious bias associated with the low sample size relative to the low vision and blind populations of the Minneapolis- Saint Paul metro area.

Orientation and Mobility training and potential disparity across subjects

Some subjects had formal orientation and mobility training facilitated by the State of Minnesota Services for the Blind and/or the non-profit Vision Loss Resources centers in the Minneapolis- Saint Paul metro area, while others did not. While this training is beneficial for safe navigation for these pedestrians, it may not fully prepare someone for surprising circumstances on the pedestrian infrastructure network, such as the various temporary obstacles and weather-based hardships such as “snow-mountains” obscuring curbs and crosswalks.

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APPENDIX A

Independent Pedestrian Navigation Focus Group Screening Questionnaire

This questionnaire will be administered during the recruitment process to determine eligibility for participation.

- What is your age?
  - EXCLUDE IF NOT 18-65
  - ASSIGN TO APPROPRIATE AGE GROUP IF 18-65

- Do you have better than 20/40 visual acuity (corrected with glasses or contacts is OK)
- Do you have 20/40- 20/400 visual acuity? Do you have acuity beyond 20/400?
  - ASSIGN TO APPROPRIATE VISION GROUP

- Do you have any history of hearing loss which inhibits every day conversation?
  - EXCLUDE IF YES

- Do you have any health problems that affect your ability or willingness to walk for personal mobility reasons?
  - EXCLUDE IF YES

- Do you live and walk in an urban area?
  - EXCLUDE IF NO

- Are you suffering from any lingering effects of stroke, tumor, head trauma, or infection? Are you aware of any cognitive deficits you experience?
  - EXCLUDE IF YES

- Can you easily phone in to a conference call or use an online conferencing service?
  - EXCLUDE IF NO
  - ASSIGN TO APPROPRIATE GROUP IF YES

APPENDIX B

Independent Pedestrian Navigation Focus Group Survey

Independent Pedestrian Navigation Focus Group Survey
Demographic and Lifestyle Questionnaire

This questionnaire asks you to indicate some details about your basic lifestyle, technology use, and mobility habit information. Please answer the following questions to the best of your ability.

Start of Block: Block 1

1 Please enter your age:

____

---

2 Please disclose your gender:

○ Male

○ Female

○ ____

---

3 What is your highest educational level completed?

○ High School / Vocational School

○ Associates Degree

○ Bachelor of Arts / Bachelor of Science

○ Masters

○ PhD

---

4 Please state your occupation, if any:

____

---

5 Which type of living environment do you live in?

○ Urban

○ Suburban

○ Rural

End of Block: Block 1

Start of Block: Low Vision only block

6 Do you know if you have normal color vision?

- ○ I have normal color vision
- ○ I do not have normal color vision
- ○ I am not sure if my color vision is normal, but I assume it is
- ○ I am not sure if my color vision is normal, but I question if I have issues perceiving color properly

7 Do you have visual field loss? If so, is it central loss? Peripheral loss?

- ○ I do not have field loss
- ○ Yes, I have central field loss
- ○ Yes, I have peripheral field loss
- ○ I do not know if I have field loss

8 Which of the following best describes your visual perception abilities?

- ◯ I have 20/40 vision or better, with or without glasses or contact lenses
- ◯ I have visual impairment that reduces my acuity to 20/40 to 20/400 (0.3 to 1.3 logMAR)
- ◯ I have visual impairment that reduces my acuity beyond 20/400 (1.3+ logMAR) , but I still use vision for mobility, navigation, and daily tasks
- ◯ I have visual impairment or vision loss that reduces my acuity beyond 20/400 (1.3+ logMAR) and I do NOT use vision for mobility, navigation, and daily tasks

Skip To: End of Block If Which of the following best describes your visual perception abilities? = I have 20/40 vision or better, with or without glasses or contact lenses

10 What is the approximate date of your last eye exam?

____

11 What is the cause of your visual impairment?

____

12 If known, please list your best acuity (with glasses or contact, such as (20/200)

13 Do you know your field of view (in degrees)?

Yes: ____

◯ I do not know my field of view

14 If you are visually impaired please check any of the following mobility aids you use:

◯ White cane

◯ Dog guide

◯ Telescope

◯ Smartphone app

End of Block: Low Vision only block

Start of Block: Mobility information

15 Do you have a driving license?

◯ Yes

◯ No, but I had one previously

◯ No

16 How often do you drive?

◯ Never

◯ Hardly Ever

◯ Weekly

◯ Most Days

◯ Every Day

17 Do you engage in outdoor walking for your personal mobility?

○ Yes

○ No

18 How often do you walk outdoors for personal mobility?

○ Never

○ Hardly Ever

○ Weekly

○ Most Days

○ Every Day

19 Please rank your primary reasons for why you walk outdoors for personal mobility, from 1 highest to 5 lowest:

_______ To get to professional obligations (e.g. Work, School)
_______ To get to personal appointments (e.g. Doctor's office, Government center)
_______ General shopping and self-sustenance activities
_______ Social reasons (e.g. meeting friends, religious events)
_______ Recreation and exercise

20 If you use a smartphone app for mobility, please list the one(s) you use:

____

End of Block: Mobility information

21 Please enter your name:

____

22 Please enter your email address for gift card forwarding information:

____

End of Survey